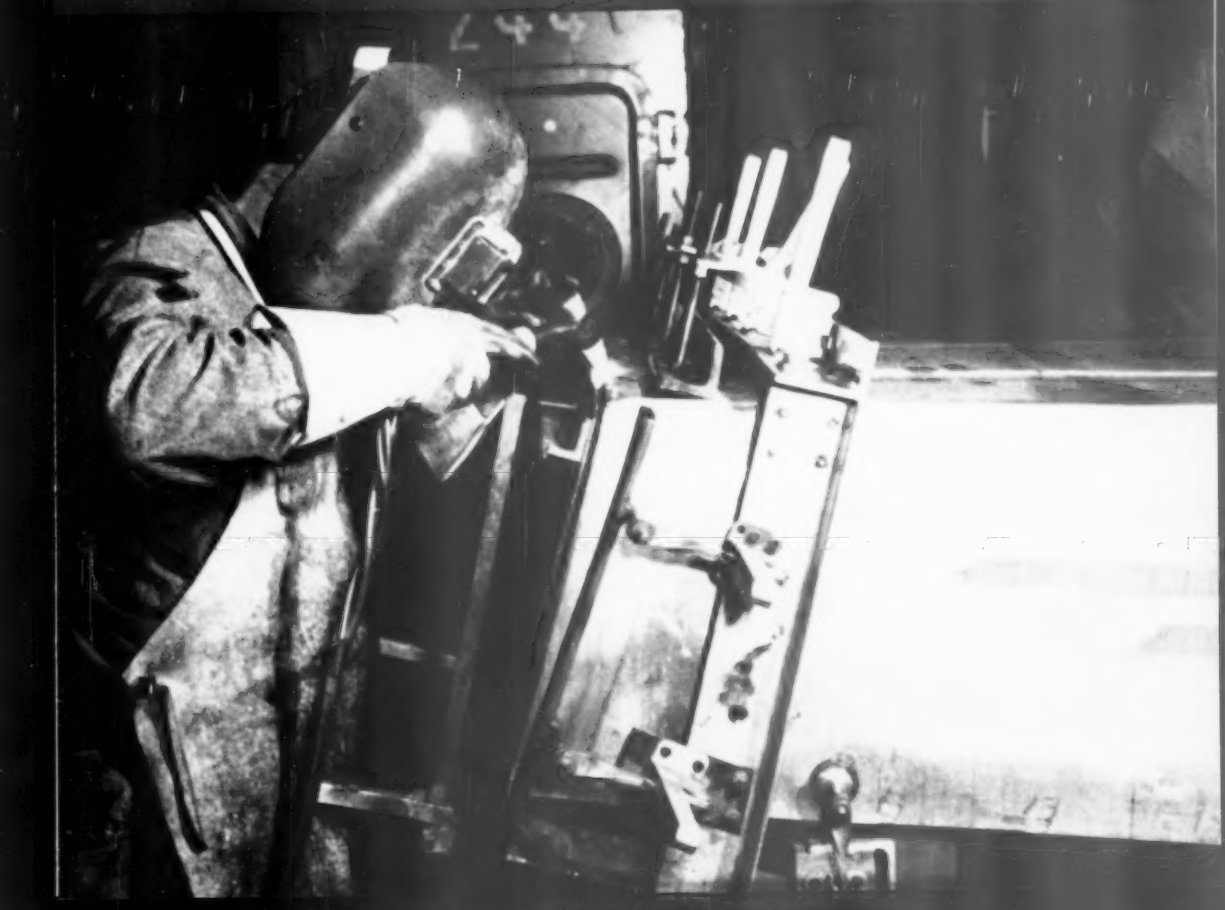
The AUGUST, 1948

WELDING JOURNAL

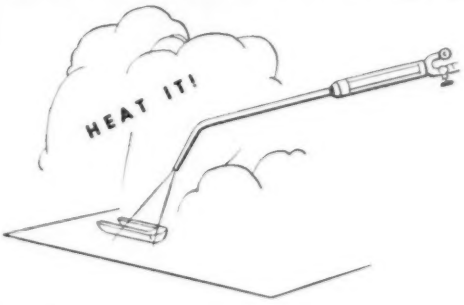
Official Publication of the American Welding Society



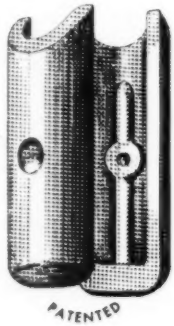
TWECO "SUPER-MEL" INSULATION

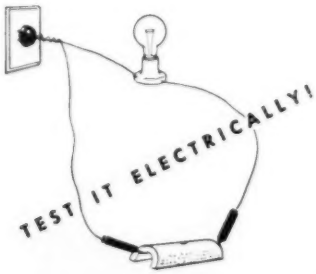
Stands abuse that ruins all other holder insulations on the market

Withstands greatest impact of all holder insulations on the market.

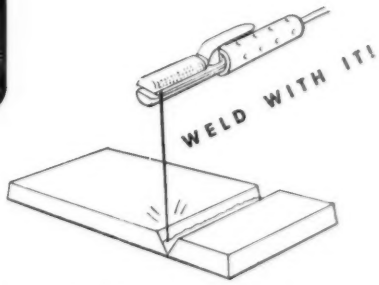


Will not carbon char even after 3 minute 6,200° F torch test.





Insulation that continues to protect your weldor and machine *after* 9,000° F arc usage. Will not pass welding current.



Long lasting! Heat defying! Insulates perfectly after heavy duty that completely destroys other holder insulations.

Tweco "Super-Mel" insulation is the secret of the superior economy and efficiency of the popular Twecotong electrode holder. Like all Twecotong tip insulations, "Super-Mel" is quickly replaceable. Top and bottom jaw tip insulators are interchangeable and can be replaced with one stock item.

Laminated glass cloth, 22 layers impregnated and molded with "Super-Mel" resin binder, produces this amazing "Super-Mel" tip insulation. The tips are so rugged that even 80% arc time under hottest possible welding conditions will not destroy their efficiency. Their patented, close fitting design (keyed to the holder) withstands tremendous impact. They are so durable and long lasting that many welderies report 50% to 300% greater useful life.

Write for Twecolog #7 giving data and prices on the complete TWECO line of electrode holders, ground clamps and cable connections for electric welding.

Tweco

MANUFACTURERS OF ELECTRODE HOLDERS • GROUND CLAMPS • CABLE CONNECTIONS FOR ELECTRIC WELDING

PRODUCTS COMPANY

ENGLISH AT IDA • WICHITA 1, KANSAS

SEE YOUR WELDING SUPPLY DISTRIBUTOR

Speedier HOBART WELDERS

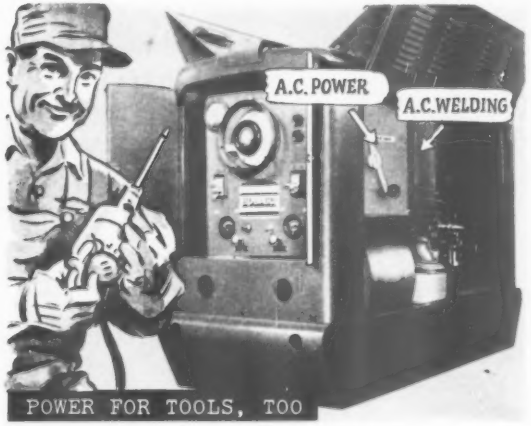
HOBART BROTHERS CO.
Box WJ-89, TROY, OHIO
"One of the world's largest builders of arc welders"

WELD EVERYWHERE

At the touch of a starter button, this husky portable 200 ampere D.C. welder does better welding faster than you ever thought possible. Also 300 and 400 ampere sizes. Use coupon for full details on the complete line of HOBART Gasoline Engine Driven Welders.

TRANSFORMER TYPE A.C.

Using extra large electrodes in the higher A.C. welding currents alone often increases speeds up to 30%. Exclusive HOBART features give added convenience, stepped-up production and lower operating costs. Get the facts on these 300 and 500 amp. welders today.



POWER FOR TOOLS, TOO

Make your own profitable A.C. power anywhere with this portable gasoline engine driven unit. Moving a switch changes A.C. Welder to A.C. Power Plant. Two sizes: 200 amp. welder or 5 K.W. and 300 amp. or 8 K.W. power plant.

TRUE REMOTE CONTROL

Adjustment of welding current at or away from the machine is another reason why it will pay you to send for HOBART'S Catalog. Also learn how to "Build Your Own" Welder with generator made for the purpose. Mail the coupon today.

HOBART

finer quality electrodes

Made to the most exacting specifications in all types and sizes for A.C. and D.C. welding. Faster welding of uniformly high quality is assured. A trial will convince you.

HOBART BROTHERS COMPANY, BOX WJ-89, TROY, OHIO

I am interested in speedier welding. Send me catalog of HOBART ARC WELDERS of _____ ampere capacity for ☐ A.C. ☐ D.C. welding ☐ Electric Drive ☐ Gas Engine Drive ☐ Generator Only

Our work is _____

NAME _____

FIRM _____

ADDRESS _____

SEE WHAT'S HAPPENED TO WELDING ELECTRODES!

Time was when you had to tackle almost every arc welding job with just one electrode. Now electrode types come by the score.

Nearly 20 years ago M & T started something with its Murex "hot rod" for downhand welding — one of the first electrodes engineered to do a specific job and do it better.

Today M & T is well out in front with the "SELECT 70."

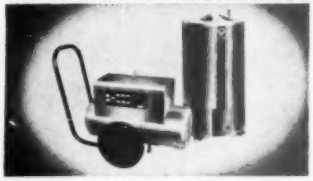
Yes, now there are 70 types of electrodes in the M & T line — each one selected from a number of designs to give top performance on a particular class of work — each one picked to help you do the best possible job, more speedily, at lower cost.

You need look no further than M & T's "SELECT 70" for easy selection of the right electrode for any application. Write today for your brief but comprehensive catalog.

METAL & THERMIT CORPORATION

120 Broadway • New York 5, N. Y

NEW ARC WELDERS BOOST AC and DC PERFORMANCE



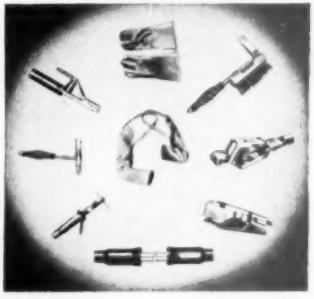
FASTER welding, better quality welds, lower power costs, and simplified maintenance are furnished by a new line of AC and DC arc welders introduced by Metal and Thermit Corporation.

Built-in capacitors for high power factor, wide current range for full rated output, and, fingertip, stepless current control for precise current setting are featured in the AC units. Available in 150 to 500 amp. models for manual arc welding, additional models for inert arc and automatic welding.

Full capacity, rugged duty DC arc welders are compact, light in weight—half the size and half the weight of older types—and are equipped with simplified current control, automatic electrode selector. Furnished in 150 to 400 amp. sets—motor driven, engine driven or belt drive.

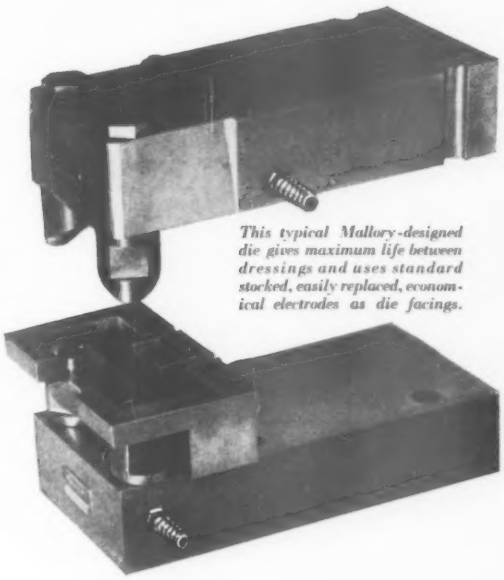
Descriptive folder gives full particulars. Address Metal and Thermit Corporation, 120 Broadway, New York 5, N. Y.

ACCESSORY DIVIDENDS DECLARED



UNDERSCORING the importance of proper accessories to top welding performance, more and more fabricators are taking pains with selection of accessories. Speedier, lower cost, safer and improved welding are assured when such items as helmets, shields, holders, connectors, cleaning tools and protective clothing are carefully selected. And more and more fabricators—sold on M & T electrode and arc welder performance — are specifying the M & T line of "accessories to the perfect weld." For descriptive literature, address Metal and Thermit Corporation, 120 Broadway, New York 5, N. Y.

Reduce Costs *on Resistance Welding Dies*



This typical Mallory-designed die gives maximum life between dressings and uses standard stocked, easily replaced, economical electrodes as die facings.

It's easy as A B C *to obtain maximum production*

A Assure yourself of a properly designed die, made with the correct facing material, properly fabricated from the highest quality materials under the most experienced and skillful supervision. *You can save with* MALLORY RESISTANCE WELDING DIES.

B Be certain that all parts fit accurately . . . that close tolerances are held on locating parts . . . that maximum cooling is used . . . that wearing parts can be easily and economically replaced . . . that alloys used will assure maximum life with minimum time for dressing on welding surfaces. *You can be certain with* MALLORY RESISTANCE WELDING DIES.

C See Mallory for the ultimate in die design and construction. Over 20 years' experience in the resistance welding alloy business is available to you in improving your present dies or completely designing and building new dies from your sample parts. *Reduce costs with* MALLORY RESISTANCE WELDING DIES.

In Canada, made and sold by Johnson Matthey & Mallory, Ltd., 110 Industry St., Toronto 15, Ontario

Resistance Welding Tips, Holders, Dies, Rod and Bars, Castings, Forgings

SERVING INDUSTRY WITH

Capacitors — Rectifiers
Contacts — Switches
Controls — Vibrators
Power Supplies
Resistance Welding Materials

P. R. MALLORY & CO. Inc.

MALLORY

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

the

WELDING JOURNAL

published for the advancement of the science and art of welding by the

AMERICAN WELDING SOCIETY

Editor

W. SPRARAGEN

OFFICERS

G. N. Sieger	*President*
O. B. J. Fraser	*1st Vice-President*
Harry W. Pierce	*2nd Vice-President*
R. S. Donald	*Treasurer*
J. G. Magrath	*Executive Secretary*
M. M. Kelly	*Secretary*
F. J. Mooney	*Asst. Secretary and Asst. Treasurer*
Simon A. Greenberg	*Technical Secretary and Handbook Editor*

DISTRICT VICE-PRESIDENTS

District #1—New York and New England
George M. Trefts, III

District #2—Mid-Eastern
Gerard E. Claussen

District #3—Southern
R. E. Lorentz, Jr.

District #4—Central
Fred L. Plummer

District #5—Mid-Western
J. R. Wirt

District #6—Mid-Southern
Ray L. Townsend

District #7—Western
Gilbert S. Schaller

volume 28 **AUGUST, 1949** *number 8*

CONTENTS

technical papers, items and reports

Heavy Cutting in the Steel Mill, by L. P. Elly 721
Current Welding Literature 727
Welding with the Aircomatic Process, by E. H. Roper 728
Welding Metallurgy—Iron and Steel, by O. H. Henry, G. E. Claussen and G. E. Linnert 731
Three-Phase, Direct-Energy, Resistance-Welding Equipment, by J. H. Cooper 741
Oxyacetylene Flame Shape Cutting in Railroad Shops, by F. B. Rykoskey 749
Should the Guided-Bend Test Be Modified? 755
Rigid-Frame Harbor Shed, by G. L. Revell 759

practical welder and designer

Arc Welding in the Mower Industry, by John A. Perry and C. A. McClean 764
Diesel Cylinder Head Repair, by J. W. Kenefic and R. E. Barber 766
How to Weld Pipe, by F. C. Geibig 767
Welded Carriers Keep the Barrels Rolling 772
Designing for Welding—Part VIII—Seam Welding, by Wallace A. Stanley 773
Butt-Welding Structural I-Beams, by F. Lang 774

society and related events

Society News 776
INDEX TO ADVERTISERS 778
News of the Industry 782
Personnel 786
New Literature 790
Employment Service Bulletin. 792
New Products 793
Abstracts of Current Welding Patents 804
Section Activities 807
List of New Members 809
Tentative Program—30th Annual Meeting 811

welding research supplement

Effect of Plastic Strain and Heat Treatment, by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston 337-s
Measurement and Relaxation of Residual Stresses, by W. Socie 354-s
Welding Rails on Ship Model Towing Basin, by W. J. Leonard 365-s
Metallurgical Aspects of Welding Mild Steel, by Nils Christensen 373-s
The Pressure Vessel Research Committee 380-s

cover: Welding in place with Argon Shielded Arc the transom for Reynolds Metals 12 foot all aluminum boat.

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Advertising office, 400 Madison Avenue, New York 17, N. Y., Telephone: Plaza 3-4466. Subscriptions $5.00 per year in United States and possessions; foreign countries $7.00. Single copies, nonmembers $.75; special issue October $1.00; members 50 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton, Pa., under the act of March 3, 1879.

Copyright 1949, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided proper credit is given.

Use Stainless Steel and HELIARC Welding

Trade-Mark

"Heliarc" welding a stainless steel water tank for use in railroad passenger coach. Welds will need no further finishing.

Switch to this Combination and Save Money

Build Sales Appeal with Stainless Steel

Get Clean, Fast Welding

Cut Finishing Costs to the Bone

Switch to the "Heliarc" process for welding stainless steel. Welding is fast, distortion is low, and there is no spatter with the "Heliarc" process. No flux is used and you save cleaning costs. The welds are so smooth that many articles need no grinding or finishing at all.

Switch to stainless steel for your other products too. They will have added strength, longer life, freedom from corrosion and better appearance. You build sales appeal into your product when you weld stainless steel with "Heliarc" equipment.

Get your free copy of the 24 page booklet, "Heliarc Welding" that tells about this clean, fast, worry-free process. Just fill out the coupon and we'll send your copy of the booklet without obligation.

The word "Heliarc" is a registered trade-mark of The Linde Air Products Company

Get your copy NOW!

The Linde Air Products Company
30 East 42nd Street, Room 1402
New York 17, N. Y.

Gentlemen: Please send me your 24 page booklet that tells about "Heliarc" welding.

Name.....Position.....

Company.....

Street Address.....

City.....State.....

THE LINDE AIR PRODUCTS COMPANY

Unit of Union Carbide and Carbon Corporation

30 East 42nd Street UCC New York 17, N. Y.

Offices in Other Principal Cities

In Canada:

DOMINION OXYGEN COMPANY, LIMITED, Toronto

YOU CAN QUICKLY CONVERT
VICTOR
WELDING TORCHES TO CUTTING WORK

This VICTOR welding torch butt Model 310 and cutting attachment Model 2450 is one of many you can use for converting from welding to cutting. No wrench needed

VICTOR attachments are made so you can change quickly from welding to cutting operations. You simply select the attachment, tip type, and tip size suited to your job and gas supply. Tips are available for oxy-acetylene, natural and city gas, and LP gases (butane and propane).

ONE TORCH HANDLES MANY JOBS

A complete range of tips and sizes permits you to use your VICTOR welding torch for such varied field and shop jobs as plate, general and heavy cutting; cast iron, rivet and boiler tube cutting; scarfing, deseaming, descaling, and rivet piercing.

VICTOR also makes regulators for all gases; a full line of machine and hand torches, cylinder manifolds, cylinder trucks, emergency pack-type flame cutting outfits, and fluxes.

Here are other VICTOR hand cutting torches. As shown, these torches come with high-pressure valve lever in 4 different positions—top, bottom, front, or rear of torch handle—so operator may choose position best suited to him. Note, too, torch head can be purchased with 90°, 75°, 45°, or straight head. Head and tube assemblies are easily interchangeable.

SEE VICTOR DISTRIBUTOR

For help in selecting the VICTOR equipment best suited to your needs, see your nearest VICTOR distributor NOW.

It costs less to own and operate VICTOR!

VICTOR
FOR WELDING

VICTOR EQUIPMENT COMPANY

844 FOLSOM STREET • SAN FRANCISCO 7, CALIFORNIA

3821 SANTA FE AVE., LOS ANGELES 11, CALIF. • 1312 W. LAKE ST., CHICAGO 7, ILL.

The WELDING JOURNAL

volume 28 August 1949 Number 8

Heavy Cutting in the Steel Mill

Torch cutting of heavy thickness with accuracy undreamed of before the War is now fairly common in the steel mill. Adequate facilities, equipment and "know how" are necessary

by L. P. Elly

IT IS not so many years ago that flame cutting of heavy material was approached with the greatest of caution, and only the most daring enthusiasts for the torch thought seriously of precision cutting of sections 12 in. thick, to say nothing of 24-in., and heavier, material. Today, accurate and exacting work on such material—although it is not done with a twist of the wrist—is commonplace. While the antecedents of heavy cutting go back 30 yr. or more, it is only from the experience of the past 15 yr. or so that we have evolved the "know how" and confidence to make it a production operation.

Today, it is a proved, reliable production tool in several phases of steel-mill work. This was probably an inevitable development, but there can be no doubt that it was greatly speeded by the war. Vastly expanded numbers and kinds of heavy-steel products were required at a time when logistic considerations permitted all sorts of radical measures to produce them. Efforts to apply the torch to heavier work with greater accuracy were stepped up out of all normal proportions, and the results were surprisingly good. So, instead of another 15 yr. of slow, hit-or-miss progress, the operation moved suddenly and rapidly into full standing.

There are two basic factors involved in what we term heavy cutting. One is, of course, thickness. The other, inevitably, is accuracy. Generally, heavy cutting will include thicknesses of material upward from 12 in., and as the thickness increases, the accuracy tolerance also usually increases slightly. There are, however, cutting jobs under 12 in. which fall into the heavy cutting category because, while only 8 or 10 in. thick, they require such precision that the working requirements are fully as exacting as on the heaviest materials. Finally, a third category of work belongs, in many ways, in the "heavy" class. This volume of cutting of moderately thick material, as represented by hot cutting on the roll line of billets or slabs, range upward from 4 in. Here the speed and quantity of work and the operating procedures also bring the job parallel with really thick materials.

In the operations of a large steel mill, we find use for heavy cutting in most of our main areas of work, these include:

(*a*) In basic production, ingot cropping and roll-line cutting.

(*b*) In finished production, riser cutting, cutting forgings before, during and after forging, shaping for machining or to final contour and shaping parts for special weldments.

(*c*) In maintenance work, a variety of spot applications.

(*d*) In the scrap yard, reducing buttons, spills, skulls, hot tops and scrap ingots to charging box size.

The torch is used in these areas of work because it saves either time or money, or because it does jobs which are otherwise practically impossible. It cuts ingots which cannot be handled efficiently by other methods. It supplements the saws and shears to maintain the pace of the roll line. It removes risers faster, cleaner, more safely. It reduces the amount or number of steps in forging and machining—sometimes eliminates the necessity for contour forging or rough machining. It roughs out complex blanks for a variety of work, particularly in maintenance operations. It reduces scrap to charging box size faster, with less handling, than other methods. These are among the reasons we find that the heavy-cutting torch pays its way.

Basically, today, the torch is the tool for heavy cutting. It would not be right, however, to disregard the uses of the oxygen lance, which was the first cutting and piercing tool in the steel mill, the first means of success-

L. P. Elly is Welding Supervisor at the Bethlehem Steel Co., Bethlehem, Pa.

This paper was presented before the Annual Meeting of the International Acetylene Association, Pittsburgh, Pa., April 25-26, 1949.

ful severance of very heavy sections, and is still a very useful facility. It is not, of course, the most economical measure for many of the operations to which it has been applied, but judiciously used, it can accomplish many otherwise impossible jobs. The lance is not actually a routine production tool for cutting, having been largely replaced by modern heavy-duty torches, but it is a reliable and versatile "spot" method, of great utility where other means reach the limit of workability.

FACILITIES

Heavy cutting, or volume cutting, requires the setting up of adequate facilities, equipment and organization to make their operations efficient, accurate and economical. These elements must meet mill requirements, which include:

(*a*) A very large volume of work
(*b*) Work spread over a large geographic area
(*c*) A variety of work, constantly changing
(*d*) Speed in turning out material
(*e*) Great mass or bulk in many jobs

To measure up to these requirements, an installation designed for heavy-cutting work must provide:

(*a*) Ample supplies of gases, well distributed
(*b*) Flexible, versatile equipment
(*c*) Logical distribution of equipment suited to the work
(*d*) Good operators, well supervised
(*e*) Proper operating supplies and facilities—templates, safety devices, controls, maintenance and repair facilities, etc.

When it is realized that the heavy cutting operations in a steel mill are dispersed in the scrap yard, foundry, forge shops, weldment shops, open hearths and rolling mills, and in random locations for maintenance as well, and that scarfing and deseaming must also be considered, it is obvious that the gas supplied must be of substantial volume at outlets over a wide area. The supply must also be constant, with reserve capacity for exceptional peak demands. Central supplies of bulk gases must be provided, with pipe-line delivery to working stations, and the system must be engineered with realistic understanding of the volumes that will be required.

For example, acetylene requirements in our experience average between 600 and 800 cu. ft. an hour in one shop alone—the Press Forge. Scrap cutting will add another 300 to 400 cu. ft. per hour, and with the other operations along similar lines of requirements, the total comes to about 3000 cu. ft. of acetylene per hour.

As a practical measure, such a supply can only be obtained efficiently with a bank of generators. Figures 1 and 2, based on a wartime installation, show something of the type of facilities required to supply acetylene in a mill where appreciable heavy cutting is added to the scarfing and general oxyacetylene load. Figure 1 shows the generator room, with three double-rated 500-lb. acetylene generators installed. These were later supplemented with a fourth unit. The generators are connected by a system of yokes to assure a steady flow from whichever generators are on the line at any given time. The carbide room in the generator house is raised so that the floor is level with the filling platform in the generator room, and the entire building is of brick fireproof construction. With three generators, the capacity of this installation was 750,000 cu. ft. per month, but the addition of an annex to a forge shop soon required the fourth generator.

Figure 2 shows the piping arrangements in the upper level of the generator room. The gas headers are $2\frac{1}{2}$-in. pipe, the downcomers to the filters are of $1\frac{1}{2}$-in. pipe, and the main supply line with shut-off valve is 3 in. Main line oxygen pressure is maintained between 160 and 200 psi., acetylene is 15 psi.

The entire pipe-line system is welded except for an occasional accessory or fitting of special nature. This simplifies erection, prevents leaks and streamlines the flow of gases. To change direction with no loss of maximum flow, we have found it advisable to bend the pipe whenever possible, and such measures, with the

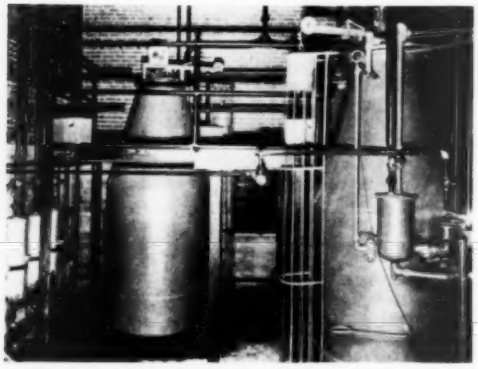


Fig. 1 General view of acetylene generator room housing three 500-lb. double-rated acetylene generators

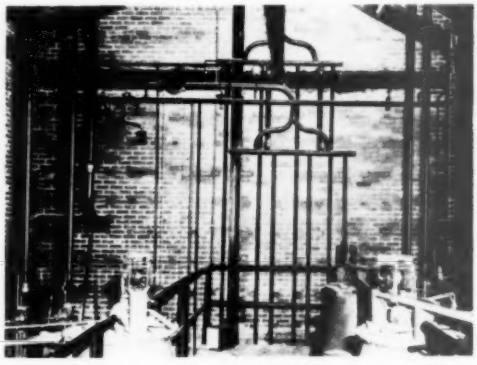


Fig. 2 Upper level of generator room

Covers removed from motors to show generator mechanisms. Note at left the spur provided for installation of a fourth generator, and all-welded piping system

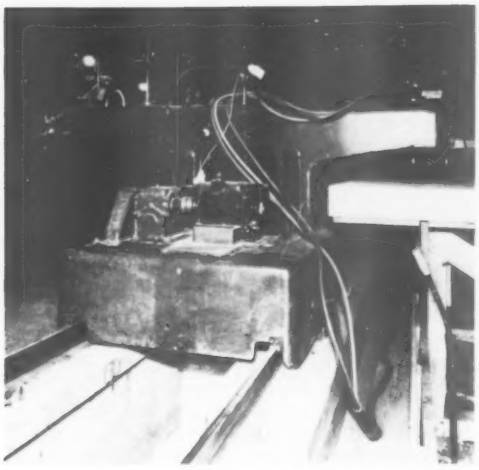


Fig. 3 Close rear view of an installation of a cutting machine of the pantograph type, showing rails, trough for hoses alongside track and repair pit

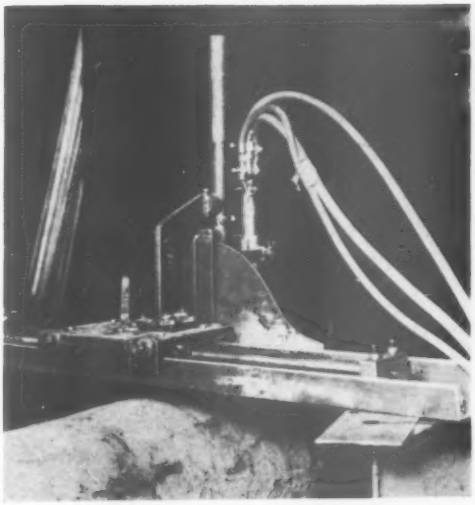


Fig. 4 Detail of an experimental wartime machine developed for severing large diameter rounds. Screw-driven torch rides semicircular cam to follow work contour

large pipe sizes and relatively high pressures used, guarantee the large constant volumes, particularly of oxygen, required for heavy cutting.

The cutting machine shown in Fig. 3 is the basic cutting machine in the mill, for both regular and heavy-cutting work. It handles most cutting jobs, straight or shape work, and can be moved readily on its rails to reduce handling operations on the massive material which is to be cut. Where it cannot be brought to the work, or the work to it, the largest portable type machines are used. They also serve as the basis for some special heavy-cutting machine, such as those used on roll-line cutting operations, which are, since the end of the war (see Fig. 4) about the only special machine setups in the mill. These semiportable cutting machines have the capacity to carry the mass of equipment required for heavy cutting, and permit an excellent degree of flexibility because the machine can be brought to the work at times when the work is all but immovable because of practical and economic considerations. The only requirement is that gas supplies be available at the working point, and provision of such supplies even where cutting is not a full-time operation is one element in design of a fully satisfactory pipe-line system in the mill.

The torches used for heavy cutting are of the heavy-duty type, often water-cooled (especially for roll-line hot cutting) and supplied by three hoses for acetylene, preheat oxygen and cutting oxygen. Since the torch is the actual working instrument of the heavy-cutting operation, it must be carefully selected to meet the requirements of the job, and it is wiser to provide excess capacity than to risk failure by forcing the work with an inefficient or undersized torch. It must also be equipped with the right tip for the job. Generally, the tips are of styles designed for heavy cutting, with heavy preheat capacity and large cutting oxygen orifices to deliver the large volumes, rather than high velocities, of cutting oxygen which experience has proved to be the key to successful heavy cutting.

In the final analysis, none of these facilities can do the work unless the men on the job know how to use them. While heavy cutting is still something of an art, much progress has been made toward a reliable working "know how," and it is possible today to train and develop good operators quite readily. It is probably too much to hope, however, that the ideal type of cutting operator, complete with know-how, experience,

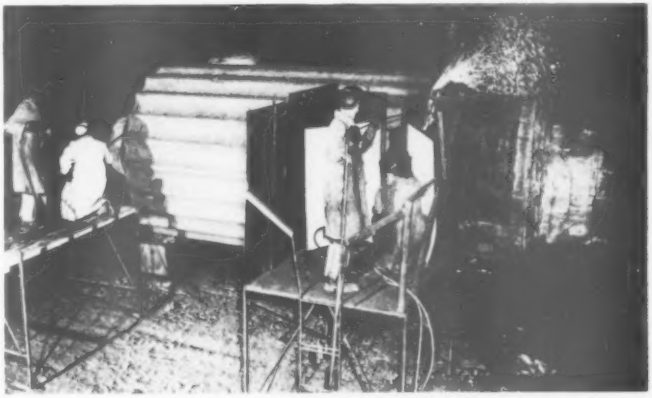


Fig. 5 Removing the hot, top and bottom stool from a 250-ton, 108-in. diameter ingot, using the lance for a cutting tool

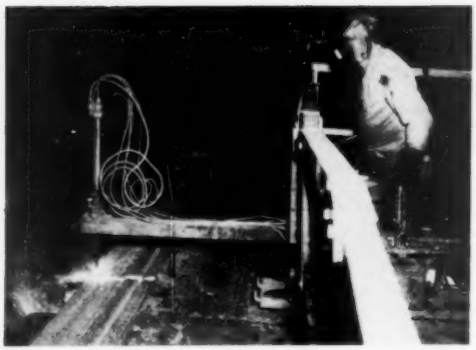


Fig. 6 Hot cutting of four 4 1/2-in. billets in the roll-line cycle

Note the automatic, hydraulically operated stop in the background and copper-tubing gas lines to the torch. Heavy-duty portable-type cutting machine, lower right corner, powers the setup.

technical knowledge and ability to handle the job on his own, will come along very often. The practical approach is development of the best operators possible with the personnel available, and provision of top-notch supervision as required by the job. The important thing in heavy-cutting work, as far as personnel is concerned, is to be sure the know how and experience are available—either in the operator or supervisor, or preferably both.

The best supervision, however, will not be enough unless every possible step is taken to train the operator. Experience under the guidance of qualified men, on-the-job learning and formal training can all play important arts. The more he can pick up of oxyacetylene fundamentals, the better, before he ever sees a heavy-cutting setup. Among the fundamentals—because he will be involved in work where they are important—the principles of oxyacetylene safe practices should be thoroughly taught to every man, and those chosen for heavy-cutting work should be men with good safety records, as well as the skill and experience in technique.

OPERATIONS

Given all these facilities of supply, equipment and personnel, the natural question is what can be expected in the way of results. A few case histories will give some idea of the answer.

The lance was previously referred to as the oldest cutting and piercing tool in the steel mill, and it is still a useful one. In the early days of heavy cutting the lance served to supplement the limited penetrating abilities of the torch. Today, even larger jobs of similar nature are torch cut to within 1 in. of the finish line.*

The lance can also be used alone at times for severance of particularly difficult sections where quality and smoothness of cut are relatively immaterial. Figure 5 illustrates such a case, in which the lance was used to crop the hot top and bottom stool from a 250-ton, 108-in. ingot. This job, while it is one of the exceptional cases for which the lance is the logical tool, is not an uncommon kind of thing in steel-mill operations. It is in such work that the lance continues to function as an important heavy-cutting method, as well as in hole-piercing and other more routine operations.

The relatively slow and clumsy lance operation draws an interesting contrast with the work in progress in Fig. 6. This is a multiple hot roll-line cutting job, on 4 1/2-in. sq. billets. While the thickness here is hardly to be considered "heavy," the speed and accuracy requirements, and the temperature of the steel (about 1800° F.) impose procedure limitations which put it, for practical purposes, in the same class of work. The setup is comparatively simple. The three-hose heavy-duty torch, with copper tubing, replacing the conventional hoses, is mounted on a square hollow bar on a heavy portable-type cutting machine. Remote controls for gases are also on the cutting-machine carriage, so that everything is at the finger tips of the operator behind his shield.

When quality is the criterion of the work, it can be obtained to a very satisfactory degree. The bevel cuts on a die block, illustrated in Fig. 7, are of excellent quality, but not particularly unusual for a good job. These cuts were made through 17 in. at a speed close to 3 in. a minute on a previously machined and finished part, and the quality leaves very little to be desired.

As thickness increases, it becomes more and more

* Helmkamp, R. F., "Automatic Oxy-Acetylene Operations," THE WELDING JOURNAL, **26** (5), 419–423 (1947).

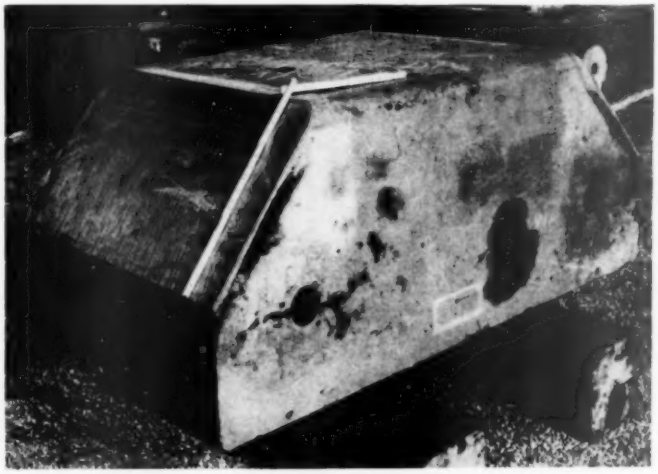


Fig. 7 Seventeen-inch bevel cut on a machined die block indicates the degree of quality possible with heavy cutting

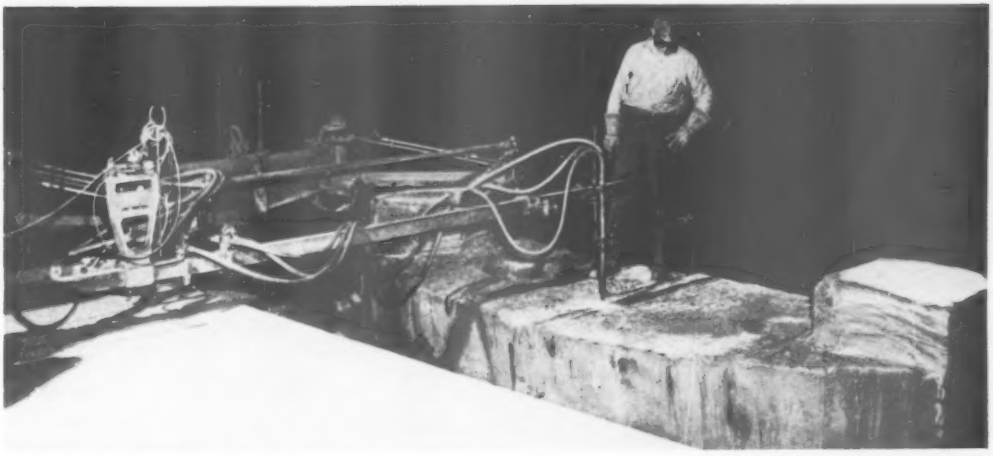


Fig. 8 Cutting through 28 in. thickness, separating a twin forging to form two cranks. Note lance-pierced and torch-cut holes

difficult to obtain such quality, although the cut faces of even 35-in. sections on massive forged cross-head slides are well up to any standards for a roughing operation, and compare well with the forged top and bottom surfaces.

The criterion on such a job must be determined according to the purpose of cutting. Whereas the bevels on the die are finishing operations, and quality is paramount even at the loss of time, the operation on the cross-head forgings is a simple matter of severance to a rough dimension, and within reasonable limits quality does not matter, while time does. Similar thinking will set the standard for each cut.

Another example of the worthwhile savings in machining which can be obtained with the torch is illustrated in Fig. 8. The piece to be cut is a rough forging, forming two cranks. Forged in pairs, they are cut apart through a section 28 to 29 in. thick and about 5 ft. long. A hole in each crank is lanced and roughed to diameter with the torch, also through the 28 in. thickness; the ends are trimmed by cutting through 26 in. thicknesses, and a post on each crank is trimmed by hand cutting to a hexagon to save on rough turning. These forgings, of alloy steel, are normalized and annealed, and preheated to 400° before cutting; air-cooled and drawn after cutting.

In a somewhat different way, forging was saved on the rudder stocks illustrated in Fig. 9. In this case, special dies would have been required to obtain the desired contour, with several varying radii, in the end of the part. Until such dies could be made up, a combination of machine torch cutting, lancing and manual cutting served satisfactorily to form the rough shape on the rather difficult contours. The torch also was used in forming the dies which were made up to complete this type of rudder stocks by forging.

For another design of rudder stock, where the die problem did not exist, the torch still played an important part in saving forging and machine work. Figure 10 shows the shaped ends of two such parts after forging in a pair, cutting apart with the torch, and removal of excess metal on the shaped end. These roughing cuts,

Fig. 9 Rudder stock after contour cutting by machine, hand torch and lance, substituting for unavailable forging dies

Fig. 10 — A second type of rudder stock, roughed on flat and bevel planes along multiple-radius contour

straight and bevel, were made on the cutting machine of the pantograph type following the constantly changing radii of the bend in the stock. The permissible margin of error in this work is very small indeed.

A routine heavy-cutting operation is the straight-line cutting to size of heavy slabs, forging blocks and ingots. While some of this work is done to ample tolerances, much of it meets dimensional limits which are, for heavy cutting, fairly exacting. The exact opposite is the case when scrapping heavy material with the torch. Here, the only objective is speed of severance, as long as reasonable economy is obtained.

It is necessary, however, to obtain as much economy as possible in scrapping operations. To this end, cutting costs in gases and labor must be kept in balance with the savings available by flame-cutting spills, skulls, ingots and other such heavy pieces. There is a definite advantage to torch cutting of these sections, and there is also a definite way of operating to obtain the best economy. Sometimes the most economical operation is the lance, or a lance and hand torch operation; sometimes a portable-type cutting machine (Fig. 11); possibly even a machine such as a travograph, can be used most economically. One of the major savings in gas-cutting heavy scrap lies in the reduction of handling steps, and either manual operations or the possible use of a shape-cutting machine will contribute much to that end. Another important element in handling is the layout of the scrapping area, which can be greatly improved by well-planned facilities. It is possible to reclaim vast quantities of otherwise useless heavy scrap around the mill with the aid of the torch, and that is a function of considerable value today.

It is, however, in precision production work that heavy cutting has made the greatest strides, and contributions to steel mill operations. The case illustrated by Fig. 12 is one of the most outstanding examples of torch assistance in a tough production job. The disk under the torch in the photograph started out as a forging ingot. After press forging in one direction toward its circular shape the ends were trimmed on a radius to provide handling clearance for cross forging. A riser of surplus metal left in the center was removed with the torch after forging, and the disk, then 15 in. thick, was gas cut to 177 in. diameter, and a $20^1/_2$-in. diameter hole burned in the center. The rough disk then was machined to $10^1/_2$ in. thickness, finish bored and rough turned to diameter. Finally, the part was returned to the cutting-machine table for the cutting of four slots, as seen in Fig. 13. These slots, $3^3/_4$ in. wide by 47 in. long, are torch cut to final dimension, allowing nothing for finishing. This part represents the ultimate in integration of forging, machining and torch cutting as cooperating production operations.

Fig. 11 — Scrapping operations with machine torch and lance

Note that work is carried on cars running across crane runway to extend laydown and working area of the scrap yard

Fig. 12 — Cutting 15-in. thick disk to 177 in. diameter with portable-type cutting machine and radius rod after forging, resulting in considerable saving of rough-machining costs

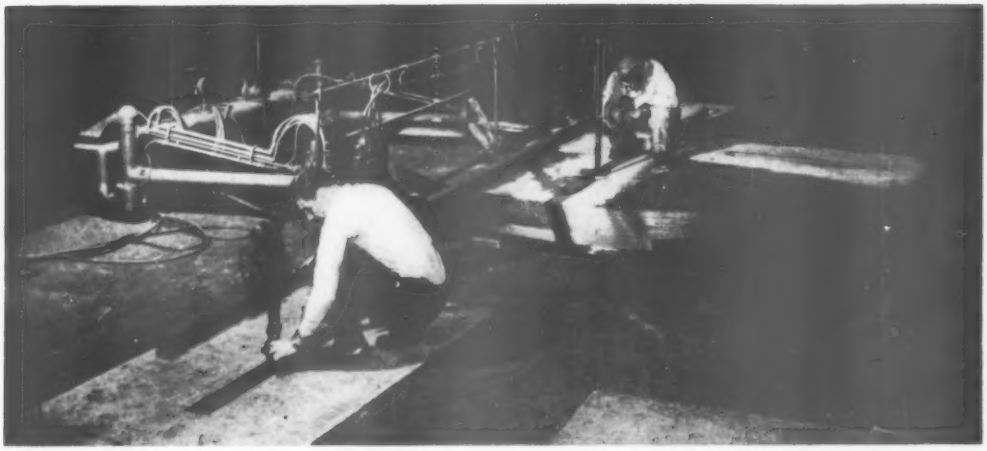


Fig. 13 Cutting slots to exact finish dimension in a 175-in. forged disk 10½ in. thick

It also points out the key functions of the torch in the mill. In this case, the torch reduced both the amount and the difficulty of forging to produce the rough part. Then it reduced the amount of machining required to finish the forging, and finally it served as a finishing tool in creating the slots directly to final size. Throughout, these functions demonstrate the modern position of the torch—its reliability, economy and accuracy in handling heavy material.

It should be borne in mind, however, that this position is almost completely dependent upon the provision and maintenance of not only adequate, but practically ideal, facilities and equipment, personnel and know how, for heavy-cutting work. In this, the maintenance of the facilities and equipment are very nearly as important as their existence. To assure reliability and accuracy, they must be kept in the best possible condition. For this purpose, in a large mill, nothing is as satisfactory as a central repair and maintenance organization, stocked with spare parts and spare cutting machines and torches, staffed with skilled and experienced specialists. With this system, on-the-spot repair work is minimized. Normal procedure is to overhaul and recondition equipment in the central shop, replacing it with spare units. With good routine maintenance in the shops, this provides constant reliability of equipment, at a minimum effort and expense. Spare parts inventories are reduced, repair work is done better and faster and the experience and skill for such work is concentrated where it can do the most good.

CONCLUSION

Experience in the last decade has brought flame-cutting operation to full-grown status for heavy work, with precision and quality or speed and economy which were hardly thought possible before the war. We may expect to see it go even further in the future. One direction will lead toward more applications of the process for precision work, wider use as a finishing or close-tolerance-roughing tool. Another will lead, very likely, toward greater economy of operation in such work as scrapping, with development of procedures for reducing handling operations and gas costs still further. Generally, as realization of the possibilities grow, we may expect to see the torch used more frequently for more operations in the mill under the increasing economic pressures which lie ahead.

CURRENT WELDING LITERATURE

Accident Prevention. Are Welding in Safety, W. W. Reddie. Welding Engr., vol. 34, no. 3 (Mar. 1949), pp. 54–58.

Airplane Manufacture. New Facts on Straightening of Welded Aircraft Structures, A. Y. Brodsky. Engrs.' Digest, vol. 10, no. 5 (May 1949), pp. 165–167.

Airplane Manufacture, Welding. Boeing's Stratojet, H. E. Jackson. Industry & Welding, vol. 22, no. 4 (Apr. 1949), pp. 38–41, 44.

Airplane Manufacture. Techniques for Spot Welding, F. S. Dever. Welding Engr., vol. 34, no. 4 (Apr. 1949), pp. 46–51.

Alloy Steel. Are You Welding Alloy Steel? T. N. Armstrong. Industry & Welding, vol. 22, no. 2 (Feb. 1949), pp. 42–44, 63–64.

Automobile Manufacture. Making Morris Minor Body. Machy. (Lond.), vol. 74, no. 1899 (Mar. 17, 1949), pp. 323–329; no. 1900 (Mar. 24), pp. 359–365.

Brazing. Aluminum Alloys. Furnace Brazing Aluminum Refrigerator Parts, J. N. Woolrich. Iron Age, vol. 163, no. 21 (May 26, 1949), pp. 62–65.

(*Continued on page 758*)

Welding with the Aircomatic Process

Additional data is presented on the Aircomatic Process for aluminum welding including detailed information on welding procedures

by E. H. Roper

IN UNDERTAKING the invention and development of a new process for metal-arc welding, an excellent starting point is the examination of existing welding methods. Such a study will show that the modern-coated electrode is often hard to beat on the score of easy deposition of quality filler metal in all positions. But the slag, in spite of its aid in producing quality weld metal, is a nuisance in the welding operation, and it must be removed afterward. Further, the work factor of a stick electrode must of necessity be low because of the time consumed in changing electrodes and removing the slag.

Those welding processes which make use of a continuously fed coiled wire can achieve very high work factors and high deposition rates, but their general use of a slagging flux make operation in other than the horizontal position impractical. Further, the manual application of these processes is limited because the operator cannot see the point of the electrode and be sure that he is properly following the joint.

Many of the difficulties caused by the fluxes in the processes mentioned are overcome by those welding methods which use a nonconsuming tungsten or carbon electrode in a shield of inert gas. The success of the gas-shielded tungsten arc method, particularly in the welding of aluminum and other hard-to-weld metals, has given the fabrication of these materials a tremendous boost. However, where filler metal is needed to make the joint properly, it must be added either manually or by a mechanical wire feeder at relatively low rates in terms of pounds per hour.

Some of the best elements of the foregoing welding methods are combined in the Aircomatic process* which gives the welding operator a manually manipulated gun with which he can deposit filler metal continuously at high rates in all positions and with an arc that he can see at all times. Since no solid flux is used there is no subsequent slag-removal operation. The equipment for the application of this method may be manually or mechanically operated.

Such equipment for Aircomatic welding and its operation are well described in THE WELDING JOURNAL of November 1948 in the article "Gas-Shielded Metal Arc-Welding Process" by A. N. Kugler and Jesse Sohn.

Because no man can hold an absolutely constant arc length, any successful manual application of a continuously fed electrode should incorporate self regulation of the burn-off rate. No method of arc-length control which relies solely on varying the wire feed speed can compensate for the irregular, rapid and unpredictable variations in arc length which occur in manual arc welding. In order to accomplish this phenomenon in a gaseous atmosphere, new concepts of gas shielding, power characteristics, wire feed speeds and current densities are required.

Relatively fine wire electrodes fed at high rates of speed are employed. At the same time voltages normal for metal arcs in gaseous atmospheres are used coupled with currents much higher than common for such small electrodes. The wire-feed speed remains constant, but variations in arc length caused by the unsteadiness of the operator's hand are instantly corrected by changes in the burn-off rate of the electrode which occur under these conditions.

In using this process the arc must be initiated and maintained within the region protected by the shielding gas. This means that the unmelted portion of the electrode must protrude but a short distance beyond the gas nozzle. Further, because of current densities which range as high as 50,000 amp. per square inch and high wire-feed speeds, it is essential that shielding gas, welding current and wire feed be applied in the right sequence and amounts in starting, maintaining and stopping the welding operation. For example, if the wire feed is set at 180 in. per minute and the wire protrudes the normal $1/2$ in. beyond the current contact tube, the wire-feed mechanism must be in operation at full speed in not over $1/6$ sec. after striking the arc. This and similar considerations make the various electrical controls necessary. The operator has only to squeeze the trigger and scratch the electrode to the

* Patent applied for.

E. H. Roper is Asst. Manager, Technical Sales Div., Air Reduction Sales Co., New York, N. Y.

This paper was presented at the Western Metals Congress, A.W.S., Los Angeles, Calif., April 11-15, 1949.

Table 1—Manual Aircomatic Welding Procedure for $^{3}/_{16}$- in., 2S Aluminum Plate

Bead sketch	*Bead No.**	*Current, amp.*	*Arc voltage*
	1	275	28
	2–4	270	30
	1–2	275	28
	3–11	270	30

Approximate Welding Data for Manual Aircomatic Welding Single-Pass, Horizontal Position Fillet Welds on Aluminum Plate Using $^{1}/_{16}$-in., 43S Filler Wire

Material thickness, in.	*Wire feed speed, in./min.*	*Current, amp., d.-c., reversed polarity*	*Arc voltage*	*Shielding gas*	*Gas flow, cu. ft./hr.*	*Travel speed, in./min.*
$^{3}/_{16}$	147	155	21	Welding grade argon	30	22
$^{1}/_{4}$	187	200	23	Welding grade argon	30	20.1
$^{1}/_{4}$	183	170	24	xx Helium	55	21

Approximate Welding Data for Manual Aircomatic Welding Butt Welds in Aluminum Plate Horizontal Position Interpass Temperature Under 300 F.

Material thickness, in.	*Filler wire size, in.*	*Wire feed speed, in./min.*	*Current, amp., d.-c., reversed polarity*	*Arc voltage*	*Usual number of passes*	*Shielding gas flow, cu. ft./hr., xx-helium*	*Travel speed per pass, in./min*
$^{1}/_{4}$	$^{1}/_{16}$	195	180	27	2	45	20
$^{3}/_{8}$	$^{2}/_{32}$	160	285	31	2	45	15
1	$^{2}/_{32}$	160	285	31	7	45	13–25

* $^{2}/_{32}$-in. filler wire and high-purity helium (45 cu. ft. per hour) wire feed speed 145 in. per minute.

work. The equipment will then operate until he releases the trigger.

All of the weldable metals have been welded using this new process. The existing commercially available equipment is for welding aluminum and its weldable alloys. As fast as items of wire supply, production models of equipment and all the details of welding technique can be worked out for other metals they will be made available.

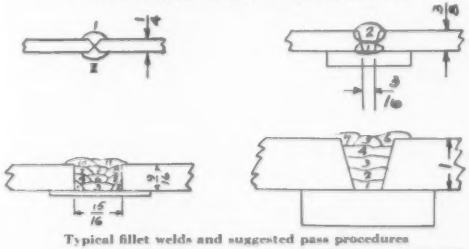
In any method of welding aluminum and its alloys, cleanliness is of prime importance. Molten aluminum has tremendous affinity for the atomic hydrogen which results when hydrocarbons or water vapor are decomposed by the arc. There is always some water vapor associated with the oxide film that forms on aluminum surfaces. Most drawing compounds contain hydrocarbons, and there is water vapor present in the atmosphere. In other words, when we arc weld aluminum there are ample opportunities for hydrogen to be formed and absorbed in the molten metal. But the solubility of hydrogen in solid aluminum is low, so as the molten metal freezes, the gas is rejected and forms porosity if it cannot escape. Hence, we need clean base metal, clean wire and clean gas for welding.

The gas-shielded tungsten-arc process has shown that the positive ion bombardment (cathode sputter) which results when the work is negative to the electrode is very advantageous as a means of removing the oxide film from aluminum. While this insures good fusion in the gas-shielded metal-arc process, it does not overcome the need for clean materials. Use of reverse polarity direct current serves to concentrate heat in the base metal and assists in securing that deep penetration that is both an asset and a detriment to this process. Even with $^{1}/_{16}$ wire as the electrode, butt welds can be made in aluminum up to $^{5}/_{16}$ in. thick with square edge preparation. On the other hand, it is difficult to weld material less than $^{1}/_{8}$ in. without burning through.

The process procedure data for manual welding of aluminum is given in Table 1.

Note that both helium and argon are used as shielding gases. The use of 99.99% helium permits higher welding speeds at equal currents and minimizes porosity. While all of our earlier work was carried out using argon, because 99.99% pure helium was not generally

Approximate welding data for manual Aircomatic welding typical butt joint designs and suggested pass procedures



Typical fillet welds and suggested pass procedures

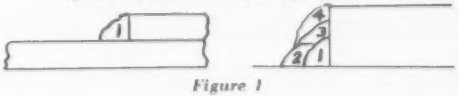


Figure 1

Table 2—Approximate Welding Data for Automatic Aircomatic Welding Typical Butt Welds in Aluminum Plate

*Plate, thickness, in.**	*Filler wire, caustic etched, in.*	*Passes*	*Wire feed speed, in./min.*	*Travel speed per pass in./min.*	*Arc voltage*	*Current, amp.*	*Gas flow, cu. ft./hr. xx-Helium***
1/2-28	1/8-28	1	126	18	30	415	100
3/4-28	1/8-28	2	112	16	30.5	380	100
3/4-618	3/16-438	1	70	7	30	500	100
1-38	3/16-28	1	92	9	34	650	125

*Degreased

**(Gas flows Not minimums)

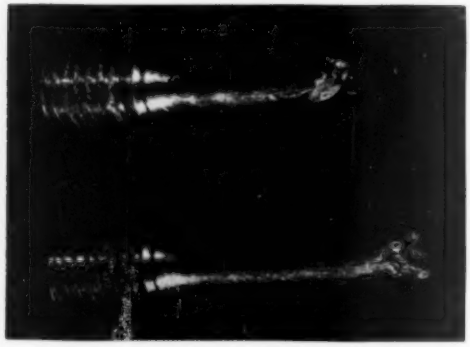


Fig. 2 0.505 all weld metal tensile specimen

Table 3—Aircomatic Welding—Automatic Physical Properties

All-weld-metal tension specimen

Wire, in.	*Ultimate strength, psi.*	*Elongation % in 2 in.*
1/8-28	17,900	25.4
3/16-438	22,450	8.4

Welded butt-joint tension specimen

Wire, in.	*Plate, in.*	*Ultimate Strength, psi.*	*Location of Fracture*
3/16-28	3/4-28	13,030	Weld
3/16-28	3/4-28	13,100	Outside of weld
3/16-28	1-38	16,030	Outside of weld

Guided-bend test specimen

Root bend—two specimens, no defects
Face bend—two specimens, no defects

available, we now prefer this latter gas. For welding thin plates (1/8-in.) downhand argon may some times be required because the arc in helium has too much energy.

Some suggested joint designs are given in Fig. 1.

The properties resulting from welds made using the suggested procedures and designs are of interest. Tensile strengths of butt welds in 2S aluminum run 16,200 to 17,300 psi. Shear strength of fillets in this material run over 17,000 psi. Guided-bend specimens show no failures, and X-rays no porosity. Welds in 52S have also passed the guided-bend tests and shown tensile strengths of 21,230 to 21,800 psi.

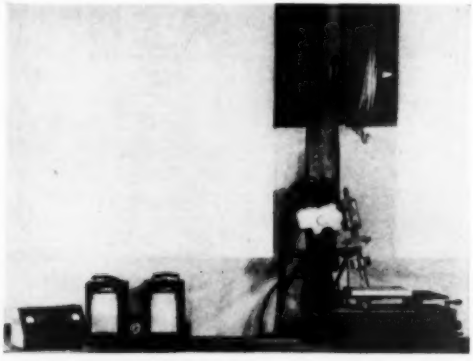


Fig. 3 Aircomatic head complete with high speed wire feed and gas shielding nozzle

Figure 2 is an all-weld metal 0.505 in. diam. specimen that broke at 15,600 psi. with 28% elongation.

Although the fine wires used in the Aircomatic Gun feed at rapid rates so that even a 1/16-in. wire will put down 10 lb. of weld metal at 100% work factor in 4 hr., mechanization of the process permits much higher deposition rates and welding speeds. In Fig. 3 is depicted the Aircomatic Head, complete with high-speed wire feed and gas-shielding nozzle. This head is of the variable speed type, maintaining arc length through arc-voltage control.

Approximate welding data are given in Table 2.

In addition to high-welding speeds the physical properties of Table 3 have been obtained. Radiographs show no porosity in the deposits.

It is hard to predict the future for gas-shielded metal arc welding. Because of its high-energy input and rapid travel speed, there results a smaller heat-affected zone and higher strength welds when applied to heat-treated aluminum alloys. The investigation of all these will take time. The welding of materials with higher melting points than aluminum requires some slight modification to the equipment. Units so adapted are undergoing field trials and the procedure data is being collected. We feel that this welding process with its speed, flexibility and ease of operation will have wide application.

WELDING METALLURGY—Iron and Steel

The Society has revised the Welding Metallurgy book originally published in 1940. The book has been brought up to date and a wealth of new material added. This book is being reproduced serially in The Welding Journal. *Copies in attractive imitation leather covers are available at $2.50*

by O. H. Henry, G. E. Claussen and G. E. Linnert

Chapter 2

TYPES OF STEEL AND THEIR MANUFACTURE

A step toward a good understanding of welding metallurgy is to become familiar with the various grades of iron and steel, their method of manufacture, and the applications for which they are particularly suited. A real effort should be made to picture the chemical composition of the materials, rather than merely memorize their specification numbers or trade designations. The manufacturing process may appear to be a subject remote from welding metallurgy, but often the melting or processing operations impart certain characteristic properties or qualities to the metal which are quite important factors when the material is welded. The characteristic properties which may be affected include the cleanliness, soundness, and the chemical homogeneity of the material.

For convenience in beginning this discussion, we can roughly classify ferrous metals into the following types:

Pig Iron
Cast Iron
Wrought Iron
Plain-Carbon Steel
Low-Alloy Steel
Stainless Steel
Heat-Resisting Steel
Tool Steel

Not all of these types are materials of construction. Pig iron is seldom cast directly into articles, but is used almost exclusively as a raw material in producing iron and steel. Since a number of these materials can be produced by more than one manufacturing method, it will be more convenient to first discuss them from the standpoint of melting process.

IRON ORE

It should be understood first of all, that metallic iron is not found free in nature in commercially usable quantities, but occurs principally in the form of oxides, sulphides, and carbonates of iron. Practically all of the iron and steel we manufacture today is secured from iron ore of the oxide type. Ore is mined and then reduced to metallic iron generally by means of the blast furnace. To be attractive for production, the ore should have a minimum iron content of approximately 50%. The impurities in the ore are chiefly silicon oxide, aluminum oxide, and phosphorus pentoxide. The two main types of iron ore are *Hematite* (ferric oxide—Fe_2O_3—red in color) mostly from northern Michigan and Minnesota, and *Magnetite* (magnetic iron oxide—Fe_3O_4—black in color) which is mined in New York and Pennsylvania.

BLAST FURNACE

The blast furnace is used to reduce iron ore to metallic iron. The product of the furnace is called *pig iron* and each batch tapped from the furnace is called a *cast*. Pig iron is used almost exclusively as a raw material in iron and steelmaking processes where it is refined in chemical composition and quality to convert it into a grade of material having useful properties.

Blast Furnace Construction

A blast furnace consists of a steel shell, about 20 feet in diameter and 90 feet high, lined with refractory firebrick in which the reduction of the ore takes place. Supplementary equipment includes a considerable amount of machinery for handling raw materials, and a series of large stoves for supplying preheated air.

Materials Charged Into Blast Furnace

The materials are charged into the blast furnace at repeated intervals to sustain continuous production of pig iron, and are shown in the following table.

Materials Charged Into Blast Furnace

Material Charged	Composition	Lbs. Per Ton Pig Iron Produced
Through the Top of the Furnace		
Iron Ore	Iron Oxide	4,000
Limestone	Calcium Carbonate	1,000
Coke	Carbon	1,700
Through the Bottom of the Furnace		
Air Preheated to 1200° F.	Oxygen 20% and Nitrogen 80%	10,000

Blast Furnace Operation

The preheated air enters the furnace through tuyeres in the furnace bottom under a gage pressure of 15–20 psi. As the ore descends, it is heated by the hot blast. About midway down the furnace, the ore reacts with the coke at about 1600° F to form iron and carbon monoxide gas.

O. H. Henry is Professor of Metallurgical Engineering, Polytechnic Institute of Brooklyn. **G. E. Claussen** formerly was Adjunct Professor of Metallurgy, Polytechnic Institute of Brooklyn, now, Metallurgist, Reid-Avery Co., Baltimore, Maryland. **G. E. Linnert**, who revised the second edition, is Senior Research Engineer, Armco Steel Corporation, Baltimore, Md.

The CO gas goes out the top of the furnace, while the iron descends still further, is melted by the combustion of the remaining coke, and forms pig iron which is tapped from the furnace at intervals.

Materials Discharged from Blast Furnace

The products from the blast furnace include more than just iron, and are shown in the following table.

Material	% Product	Composition	Use
	Through the Top of the Furnace		
Gas	75%	CO, CO_2 N_2	Fuel gas
Flue Dust	2%	Carbon and Iron Oxide	Recharged into furnace
	Tapped Out at the Bottom of Furnace		
Slag	10%	Ca, Al, Mg Silicates	Road fill, cement, or discarded
Iron	13%	C, 4.0% Mn, 1.0% Si, 2.0% Fe, bal.	Iron and steel production

If the molten iron from the blast furnace is cast into crude bars it is called *pig iron;* if carried directly to a Bessemer converter, open-hearth, or electric furnace in the molten condition it is referred to as *hot metal.*

CUPOLA

The cupola is a type of foundry furnace used for producing cast iron, and is built somewhat like a miniature blast furnace. The raw materials charged into the cupola are: (1) coke, as a source of heat; (2) pig iron and steel scrap, for metal; and (3) limestone, as a flux and slag covering. An unheated air blast is forced through tuyeres in the lower part of the cupola to burn the coke and melt down the charge.

The composition of the metal produced may vary considerably depending upon the grade of pig iron and scrap used, but is generally quite high in carbon content, perhaps about 3.0 percent. By adjusting the remainder of the composition, that is, the Mn, P, S, and the Si with additions of ferroalloys, etc., the mode and distribution of the carbon in the iron *as cast,* or after a subsequent annealing treatment, can be controlled to produce white cast iron, gray cast iron, or malleable cast iron.

WROUGHT IRON

While wrought iron may be regarded by some as a material of bygone days, it is still being produced in considerable quantity and takes preference over our more modern steels in certain applications. We frequently are called upon to weld wrought iron pipe.

Originally, wrought iron was produced in reverberatory hearth furnaces by melting pig iron and added slag. The metal bath was decarburized with roll scale (iron oxide) and the slag and metal puddled together into pasty balls. The balls were next compressed in a squeezing machine to remove excess slag, and to form a bloom suitable for rolling into bars or shapes. More modern methods of producing wrought iron involve the mixing of refined metal from a Bessemer converter with a selected open-hearth slag.

Wrought iron therefore consists of about 1 to 4 percent by weight of a slag component dispersed as elongated stringers in a matrix of low-carbon steel, or *iron.* The slag consists mostly of iron oxide and some silica. The *iron* matrix analyzes about 0.08% cabron, 0.05% manganese, 0.15% phosphorus, 0.020% sulphur, and 0.10% silicon, the remainder being iron.

SIGNIFICANCE OF *ACID* AND *BASIC* STEELMAKING

Before proceeding further with our description of steel making processes, it appears wise to discuss the matter of acid versus basic processes, for an understanding of these terms is an important piece of metallurgical knowledge. The terms *acid* and *basic* are derived from the kind of refractory lining and slag employed in a particular process. We might first point out that most of the non-metallic compounds used in making refractory furnace linings, or employed as a flux or slag, can be classified as having acid or basic (alkaline) characteristics when heated to steelmaking temperatures. The classification of a material is made by noting any tendency on its part to react with a strongly *basic* material like lime (CaO) or a decidedly *acid* material like silica (SiO_2). Unlike materials will react or attack each other, while like materials will not. For this reason, a furnace operating with a basic type slag will have a refractory lining made of basic materials, whereas a furnace using an acid type slag will have a lining of acid materials. Should an acid slag be used in a basic lined furnace, the slag would quickly attack and damage the furnace lining. The common acid type materials involved in steel melting are silica (SiO_2) and phosphorus pentoxide (P_2O_5), while the basic materials are lime (CaO), burnt dolomite (MgO.CaO), iron oxide (FeO) and manganese oxide (MnO).

With the derivation of the terminology settled, we can now point out the important differences of acid and basic steelmaking processes. The chief difference lies in their respective ability to rid the molten metal bath of residual phosphorus and sulphur. In the acid steelmaking furnace there can be no significant removal of phosphorus and sulphur because the acid type slag cannot react chemically with these two elements. Consequently, the charge of raw materials as a whole must meet the same maximum requirements specified for these two elements in the finished steel. This means high-grade ore and scrap must be used. For the most part then, acid-lined furnaces are used to produce high-quality steels and function mainly as a furnace to melt a charge and hold it while non-metallics rise from the bath into the slag.

On the other hand, a basic steelmaking furnace can remove almost any reasonable amount of both phosphorus and sulphur from the molten bath by means of its basic slag. The chemistry of this phase of steelmaking is tremendously complicated, but the fundamentals can be stated simply. First of all, the lime (CaO) in the slag is the all-important basic constituent. The removal of phosphorus is accomplished by oxidation. The phosphorus pentoxide which forms then rises into the slag where it forms a calcium phosphate compound. Sulphur is removed in two ways; through the formation of manganese sulphide (MnS) which rises into the slag, and by direct absorption into the slag. However, in either case the sulphur is held in the slag as calcium sulphide (CaS), the calcium, of course, being secured from the lime.

BESSEMER CONVERTER

Bessemer steel is manufactured in a converter. The term converter is used instead of furnace because it is not equipped with a source of heat to melt down a charge of cold scrap, but must receive a charge of molten pig iron direct from the blast furnace. The converter may be lined with an acid or basic type of refractory brick, and the type of lining is, of course, an important factor in determining how the converter shall be operated to refine the pig iron in chemical composition. The acid-lined converter is the more widely used type in the United States.

Bessemer Converter Construction and Operation

The construction of a typical Bessemer converter is shown in Fig. 5. It consists of a tilting vessel about 9 feet in diameter, 12 feet high and has a perforated bottom, the holes being about $^3/_4$ inch in diameter. While the converter is tilted on its side, molten pig iron is poured in. As the converter is righted a blast of air (not heated) at 20 psi is blown through the holes and the molten steel. The oxygen in the air reacts first with the silicon and the manganese, removing them to the slag (iron-manganese silicate), which floats on the metal. Then the carbon is oxidized to carbon monoxide which in turn burns to carbon dioxide in a long blue flame from the mouth of the converter. The combustion of the silicon, manganese, and carbon raises the temperature of the metal in the converter. When the carbon flame dies out, a point in the process known as the *carbon drop* which occurs between 12 and 18 minutes after the start of the converting process, the vessel is ready to be emptied. Each batch of converted metal is now known as *blown metal* and the whole operation or *blow* is generally numbered consecutively for identification.

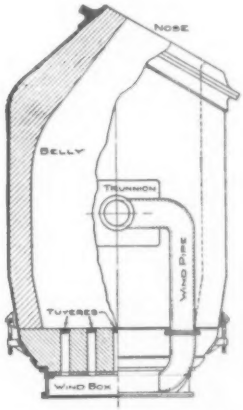


Fig. 5—A Bessemer Converter (Hayward)

In an acid-lined converter, the silicon, manganese, and carbon contents can be reduced to astonishingly low percentages. A typical raw Bessemer steel, that is, before recarburization or silicon deoxidation, would be 0.03% carbon, 0.05% manganese, and 0.01% silicon. The phosphorus and sulphur contained in the pig iron charge are not removed because oxidation (the air blast) is not continued after the carbon is removed. Also, the highly basic slag needed to hold the phosphorus and sulphur as calcium compounds is absent. Therefore, acid Bessemer steel is characterized by high phosphorus content, up to 0.13 percent, and usually high sulphur content. Because of the tremendous quantity of air blown through the metal, the nitrogen content is also higher than in other types of steel.

Practically all Bessemer steel is of the plain-carbon steel grades. The major tonnage is used as pipe, skelp, tin plate steel, steel wool wire, and free-machining steel. In the latter material, sulphur is added as the free-machining agent in quantities from 0.10 to 0.35 percent.

Although the basic-lined Bessemer converter is used very little in the United States, it is important to know that this type converter performs in exactly the same way as the acid-type converter except the basic process uses a highly basic slag of lime, which is added immediately after the silicon, manganese, and carbon have been removed, to dephosphorize the metal.

OPEN-HEARTH FURNACE

The major tonnage of steel produced in the United States is made in basic open-hearth furnaces. This process is capable of producing metal ranging from nearly pure iron to high-carbon medium-alloy steel. An acid-type lining and slag also may be used in an open-hearth furnace, but the acid process is used to produce only a small tonnage of steel. The open-hearth is a batch furnace, and each batch of steel tapped from the furnace is called a *heat*. Identification numbers are assigned to each heat, which frequently indicate the particular melting furnace used, the year of manufacture, and the consecutive numbered heat melted. By retaining this heat number on steel products, the complete chemical analyses and processing history of the material are available at any time in the mill records.

Open-Hearth Furnace Construction and Operation

The construction of a basic open-hearth furnace is shown in Fig. 6. It consists principally of a shallow pan or hearth about 15 feet wide, 45 feet long, and 3 feet deep.

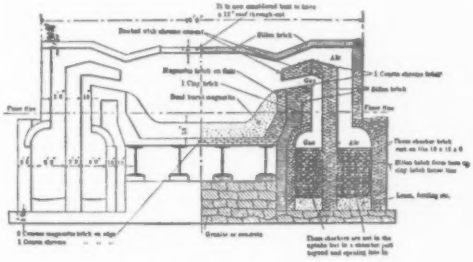


Fig. 6—An Open-Hearth Furnace (Stoughton)

The most commonly used basic refractory lining for the hearth is dead burned magnesite (MgO). A furnace of this size will produce a 150-ton heat of steel every twelve hours. The fuel used for melting the charge of raw materials may be powdered coal, gas, or petroleum oil. The air used to burn the fuel is preheated in the heat exchangers or *checkers* situated below the furnace. The checkers operate on a regenerative cycle utilizing the hot exhaust gases from the furnace. The making of a heat in an open-hearth furnace can be broken down into three operational parts: (1) charging and melting, (2) refining, and (3) finishing and deoxidation.

Charging and Melting

The raw materials charged into the open-hearth furnace may consist of (1) cold materials entirely, such as pig iron, and iron and steel scrap, (2) hot molten metal, as supplied directly from a blast furnace or Bessemer converter, or (3) combinations of cold and hot materials. In addition to the metal charge, limestone is added as a flux and slag former. A suitable charge is melted down to form a bath about 30 inches deep, upon which floats a basic (lime) slag about 6 inches deep. The bath of molten metal and slag is open to the hot gases of combustion passing over it, whence the name *open-hearth*.

Refining

In refining the molten bath, liberal amounts of oxygen

are available to the metal by adding iron ore, mill scale and limestone. As a result, the silicon, manganese, carbon, and phosphorus in the bath are oxidized, and their reaction products either rise into the slag or, in the case of carbon, escape as a gas. Sulphur is relegated to the slag by means described earlier in this chapter. The control of the reactions in the metal bath and slag is a very complex operation, and is highly dependent upon the composition of the bath, the condition of the slag, and their temperature. Slag control is particularly difficult. Additions of lime are frequently made to counteract the acid silica and phosphorus pentoxide entering the slag and thus maintain sufficiently strong basicity.

Finishing and Deoxidation

At the end of the refining period, that is, when the Si, Mn, C, P, and S contents have been reduced to the desired levels, the metal bath is saturated with oxygen, or, more accurately, iron oxide. The amount of oxygen present is dependent to a large extent upon the carbon content of the metal bath; the greatest amount of oxygen being held when the carbon content is the lowest. At any level of carbon, however, the amount of oxygen present is far in excess of that which could be accommodated in the metal after solidification. Consequently, to avoid the formation of large gas pockets in the cast metal, a substantial portion of this oxygen must be removed. There are three general ways of handling a heat of steel to accomplish oxygen removal, and each way produces a characteristically different kind of steel for a given chemical composition.

Rimmed Steel—This perhaps represents the oldest way of dealing with oxygen, and it is still used in producing a large tonnage of steel. The making of rimmed steel consists of pouring the oxygen-bearing metal into the usual cast-iron ingot molds. The ingot commences to solidify by depositing a crust of nearly pure iron on the walls and bottom of the mold. As a result, the remaining liquid steel is enriched slightly with carbon, which in turn reacts with some of the oxygen to form carbon monoxide gas.

Much of the gas rises and escapes from the top of the ingot with a fiery shower of sparks. The remainder of the CO gas is trapped in the solidifying metal. This cycle of (1) iron freezing on the mold walls, and (2) the segregated carbon reacting with the oxygen, will continue until an outer skin or *rim* of iron about 3 inches thick is formed. Then the *rimming* action is stopped by the loss of temperature and completion of solidification. Rimmed steel is therefore characterized by a skin of nearly pure iron around the outer periphery of the cross section and a central segregated core which contains practically all of the carbon, phosphorus, and sulphur. This peculiar pattern of segregation persists through forging, rolling, and forming operations and is responsible for the successful use of the material in its many applications. Its chief advantage is the excellent defect-free surface produced by the pure iron skin. Rimmed steel is used in making plate, sheet, and wire; much of the latter being used for welding rod and electrode core wire. Steel containing more than approximately 0.30 percent carbon cannot be furnished as rimmed steel because the amount of oxygen held in the molten condition is not sufficient to support the rimming action.

Killed Steel—As a second way of dealing with oxygen in molten metal, the bath may be deoxidized by adding elements whose affinity for oxygen is greater than that of iron, and whose oxides are easily eliminated from the bath. Some of the elements which can be used to serve this purpose are silicon, aluminum, titanium, calcium, and zirconium. In actual practice, silicon in the form of ferrosilicon alloy is added to the furnace to remove the greater portion of the oxygen. The silicon combines with oxygen to form silica (SiO_2) which rises into the slag. If necessary, more thorough deoxidation results by adding stronger agents, such as aluminum, ferrotitanium, or calcium-silicon alloy. It is important to know that the properties of steel can be markedly influenced by the particular deoxidation practice used. For example, the grain-coarsening characteristics can be controlled by adding measured amounts of aluminum. An amount somewhat in excess of that required for complete oxygen removal will tend to inhibit grain growth. Killed steel is poured into molds fitted with a refractory top. The metal solidifies very quietly to produce a sound ingot with a pronounced shrinkage cavity or pipe in the upper end encompassed by the refractory hot-top. After shearing off this piped upper portion, the remaining ingot is dense and homogeneous.

Semi-killed Steel—As the name indicates, this way of dealing with oxygen represents a compromise between rimmed and killed steel practice. A small amount of a deoxidizing agent, generally ferrosilicon or aluminum, is added to the metal either in the furnace, the ladle, or the mold. The amount is just sufficient to kill any rimming action, and yet leaves some dissolved oxygen. The evolution of this oxygen upon solidification of the metal tends to offset shrinkage and minimizes the shrinkage cavity or pipe in the top of the ingot. Frequently a heavy steel plate or cap is placed on the top of the ingot just after pouring to freeze a skin over the top. Any pipe which forms below this skin is, of course, shielded from the air and is kept free of oxide or slag. This cavity is called *secondary pipe*, and is welded up by the subsequent hot working operations. Semi-killed steel has a number of desirable properties, but the chief reason for its production is the high yield of usable material from the ingot.

Comparison of Rimmed, Semi-killed, and Killed Steels

	Rimmed	Semi-killed	Killed
Carbon Content	Up to 0.3%	Up to 1.0%	Up to 1.5%
Silicon Content	Less than 0.01%	0.01 to 0.10%	Over 0.10%
Primary Piping (Shrinkage)	None	None	Severe
Porosity	Considerable	Considerable	None
Segregation	Pronounced	Little	Very little

Further discussion of these kinds of steel and their relation to welding will be made in later chapters.

ELECTRIC-ARC FURNACE

Electric-arc furnaces may vary considerably in design and size. The type most commonly used has a circular dished bottom for holding the metal bath, and the heat is supplied by arcs between three carbon electrodes and the surface of the molten metal. Furnace linings of burned magnesite (MgO—basic) or chrome brick (Cr_2O_3—weakly acid) are generally used, although foundries producing castings may employ acid linings of silica (SiO_2).

The charge may consist of steel scrap, pig iron, ore, and alloys. The surface of the bath, except at the points where the arcs are burning, is covered with a blanket of slag. The electric-arc furnace offers excellent opportunities for the control of steelmaking reactions since very high temperatures can be attained, close regulation of temperature can be exercised, and the bath cannot be contaminated by the fuel. Slag composition can easily be altered by making additions, or by complete removal and replacement.

It is more expensive to melt steel in an electric-arc furnace than in the open-hearth or Bessemer and therefore only special grades of steel are produced. This would include all stainless and heat-resisting steels, and those plain-carbon and low-alloy steels which are required to meet special requirements. Typical examples would be steels for aircraft engine manufacture which must meet rigid tests for soundness, steels for welding electrodes which must fall in extremely narrow chemical composition ranges, steels for ball bearings and bearing races which must be unusually free from non-metallic inclusions, steels for valve springs which must be of superior quality in all respects—including low phosphorus and sulphur contents.

ELECTRIC-INDUCTION FURNACE

The high frequency or coreless induction process is used mostly in melting stainless steels, special tool steels, and other unusual alloys, such as the cobalt base or nickel base heat-resistant alloys. The furnace consists of a coil (for example, 40 turns, 12 inches in diameter, 2 feet high) of water-cooled copper tubing, which acts as the primary of an air transformer. The secondary is the metal to be melted which is contained in a crucible inside the copper coil. The crucible may be made of any good refractory: silica, alumina, magnesite, etc. A high-frequency current (1000 cycles, 300 kw for a charge of $^1/_2$ ton) passes through the coil which induces similar high-frequency currents in the outer portions of the charge, which consists of chunks of metal whose size and shape are governed by the dimensions of the furnace. The heat from the outer parts of the charge is conducted to the center and the charge usually melts within one hour. On account of the strong stirring action created by the high-frequency current, only a few minutes are required for refining after which the steel is poured into ingots or castings. The chemical composition of the metal poured is essentially the same as the material charged. No attempt is made to dephosphorize or desulphurize. Only small losses of oxidizable elements like chromium, manganese, or silicon are incurred.

MILL PROCESSING

The finished molten steel from these steelmaking furnaces can be utilized in two possible ways: It can be cast directly into an article of the desired shape, which is the work of a foundry; or it can be cast into a large block of steel called an ingot, which is reduced to the desired size and shape by steel mill processing operations.

Foundries use many kinds of furnaces for producing articles of cast iron and cast steel: the cupola, open-hearth, electric-arc furnace, and so forth. The selection of a furnace is guided by the composition of the steel to be melted, the amount of metal required, and the quality standards to be met. Although the mechanical properties of cast steel are generally inferior to those of wrought steel, there are many other advantages in producing castings which justify their manufacture. Lately, the use of welding to assemble cast components has increased considerably.

Ingots

The molds into which the molten steel is poured to form ingots are made of cast iron. The mold walls may measure as much as 6 to 10 inches in thickness. The inside surface of the mold is frequently coated with tar, pitch, aluminum paint, or some similar preparation, to help form a smooth ingot surface free of defects. The cross-sectional shape of the ingot will vary depending upon the intended product. Rectangular ingots are used for making slabs, plate, and sheet, and the ingots may weigh as much as 25,000 pounds each. Square ingots are used for producing billets, structural shapes, bars, and rods. The walls of the mold are often corrugated or fluted to promote soundness in the ingot upon solidification. In order that the ingot may be stripped (removed) readily from the mold after solidification, which usually takes about an hour, the ingot tapers over its length. The molds used in making rimmed or semi-killed steels may be either big-end-up or big-end-down. Killed steel is always cast into big-end-up molds because of the refractory hot-top which is fitted to the top of the mold.

Hot Working

Ingots, after being stripped from the mold, may be placed in stock, or sent directly to furnaces or heated pits (soaking pits) for equalization of temperature throughout their mass and heating to the proper temperature for hot working. The hot reduction of the ingot may be carried out by forging, pressing, or rolling. The greater tonnage of steel is finished by hot rolling. Forging and pressing for the most part are used as preparatory operations to rolling when handling very highly alloyed steels which are difficult to hot work without cracking.

Rolling mills can be classified as *roughing mills* or *finishing mills*, and are generally designed to produce a particular type of product. The common classification of hot-rolled mill products is as shown below.

Blooms, billets, slabs, and sheet bar are semi-finished products of roughing mills. Bars, structural shapes, sheet, strip, and rods are considered finished steel products. Rolling mills can be classified into two general types: reversing and continuous. A reversing mill consists of only one frame or stand of rolls. Usually only two rolls, one above the other, are used. These rolls can be quickly adjusted to produce material of varying thickness, and their direction of rotation can be quickly reversed. Many roughing mills are of the reversing type. An ingot is reduced by passing it back and forth through the stand while the rolls move closer together for each successive pass. On the other hand, a continuous mill consists of a number of roll stands. The distance between the rolls is fixed, and decreases progressively from the first stand to the last. The stands may be placed in a line for straight-through production of the rolled product, or placed side by side so that the product shuttles back and forth. Some mill stands may contain three rolls, each one above the other. The product first passes through the lower pair of rolls; it is then returned through the upper pair. Vertical rolls are sometimes used to control the width of the product as it emerges from a pair of horizontal rolls.

Classification of Hot-Rolled Mill Products

Ingots	Any shape, *as cast*
Blooms	Cross-sectional area 36 sq. in. min., usually square or rectangular
Billets	Cross-sectional area 36 sq. in. max., $1^1/_2$ in. min. cross-sectional dimension
Slabs	Cross-sectional area 16 sq. in. min., $1^1/_2$ in. min. thickness, width at least twice thickness
Structural Shapes	Channels, I-beams, angles, etc.
Bars	Rounds, squares, hexagons, and flats
Rods	About $^3/_8$ in. diameter round and smaller, hot rolled
Plates	Thickness $^3/_{16}$ in. min. and of substantial width
Sheet	Thickness $^3/_{16}$ in. max. and of substantial width
Strip	Up to $^1/_4$ in. thick and 12 in. width

After being rolled the steel is cooled according to its characteristics. The common grades are simply cooled in air or racks to prevent distortion. Highly hardenable grades are slowly cooled by burying the bars or shapes in an insulating material. Certain grades of stainless steel are quenched in water. The hot rolling operation affects the material in a number of ways; it welds together the deep-seated clean blowholes and secondary pipe, reduces the grain size of the steel, improves the toughness and ductility, makes the material more homogeneous in chemical composition (but does not eliminate marked segregation), and imparts directionality in the steel (like fiber in timber). In the rolling mill about 25 percent of the weight of the original ingot is lost through shearing off the hot-topped and butt portions.

Cold Finishing

The term *cold finishing* can apply to a number of final operations in a steel mill; polishing, straightening, grinding, and so forth. However, we are primarily interested in two methods which may be used to reduce the size or cross-sectional shape of a piece of steel while it is cold. This kind of cold finishing is employed for a number of reasons, amoung them being (1) better accuracy and uniformity of cross-sectional size and shape, (2) smoother surface finish, (3) increased strength at a small sacrifice in ductility, and (4) easier production of complex shapes. The first method is *cold rolling*, or the rolling of cold material between heavy, hardened rolls in much the same manner as hot rolling. The amount of reduction that can be made in a cold-rolling pass is, of course much less than can be made by hot rolling. The second method of cold finishing is *cold drawing*, or the drawing of the material through a hardened die. Cold-drawing dies consist of a block of extremely hard material containing a tapered hole. The smaller orifice conforms to the desired final size. The bar to be drawn is coated with a lubricant and either pushed or pulled through the die opening.

The customary practice is to cold roll sheet and strip material. Bars can be either rolled or drawn, although drawing is the most widely used method for finishing bars. It is important to mention that the smallest size bar or rod that can be commercially hot rolled is about 0.200 inch in diameter. Therefore, to produce smaller diameter material our only recourse is to reduce the hot-rolled rods by cold drawing, which of course results in *wire*.

TYPES OF STEEL

In the preceding parts of this chapter we first presented a simple list of the types of irons and steels and then described the processes which could be used for their manufacture. We are now in a position to describe in more detail those materials which are of interest to us from the standpoint of welding.

Plain-Carbon Steel

This variety of materials comprises the greatest part of steel manufactured and used. Plain-carbon steels may contain varying amounts of carbon, manganese, phosphorus, sulphur, and silicon—often referred to as the "big five" when discussing analyses. Of course, small amounts of such elements as aluminum and titanium may also be present as deoxidizers. However, the addition of substantial amounts of manganese (over 1.50%), chromium, nickel, molybdenum, etc., will relegate the steel to the *alloy* classification. It will be recalled that plain-carbon steel can not only be manufactured in several different kinds of furnaces, but also can be furnished as rimmed, semi-killed, or killed steel. Both the furnace used and the finishing practice will have an effect upon the characteristics and properties of the steel. The greatest change in properties, however, is brought about through variations in the element carbon. Increasing carbon content leads to marked increases in hardness and strength. Classified according to carbon content, we have:

Classification and Usage of Plain-Carbon Steels

Carbon Content	Common Name	Examples of Usage
0.03% max.	Armco Ingot Iron	Enameling, galvanizing, and deep drawing sheets
0.15% max.	Low-Carbon Steel	Welding electrodes and rods. All-purpose wire
0.15/0.30%	Mild Steel	Structural shapes and bars
0.30/0.50%	Medium Steel	Machine parts and tools
0.50/1.0%	High-Carbon Steel	Railroad rails, springs, and dies

Low-Alloy Steel

Low-alloy steels were a natural outgrowth from the plain-carbon variety when it was found that relatively small additions of alloying elements produced remarkable improvement in properties. Unfortunately, no one element represented a panacea, and it was necessary to study the influence of each alloying element and make judicious additions of one or more to secure the desired results. Alloying elements are added to iron and steel for many reasons, among them being: (1) to improve mechanical properties (strength and toughness), (2) to increase or decrease propensity to hardening during heat treatment, and (3) to retard rusting or corrosion. The more commonly used alloying elements are nickel, chromium, molybdenum, phosphorus, copper, and vanadium. The functions of these and many other elements are described in detail later in this book.

There are a vast number of low-alloy steels on the market already, and new grades are being introduced regularly. However, the majority of these materials fall into the following general classifications:

Constructional Steels—In order to reduce dead weight in the construction of storage tanks, railroad cars, truck frames, crane booms, etc., a group of low-alloy steels, commonly referred to as "high-tensile" steels, have been developed. These materials have higher tensile and yield strengths than found in ordinary mild steel or structural steel and make it possible to use a lighter section to meet a given strength requirement. Only small amounts of alloying elements are used. The carbon content is usually held at a low level to avoid difficulty in welding. Many of the materials are proprietary alloys, and have been marketed under such trade names as Cor-Ten, Yoloy, R.D.S., Mayari R, and so forth.

Automotive and Machinery Steels—A wide variety of standardized steels have been developed chiefly through the efforts of the Society of Automotive Engineers. These *SAE* steels make use of a number of alloys and combinations of alloys. Many of the alloy combinations are available in a wide range of carbon contents.

Steels for Low-Temperature Service—New instances arise every day wherein metals are required to perform at low temperatures. As examples we can mention road grading equipment operating at −20° F in Alaska, aircraft flying in a stratosphere of −60° F and pressure vessels holding liquefied gases at −320° F. Ordinary mild steel or structural steel exhibits poor ductility and impact strength at these low temperatures and is an unreliable material in such critical applications. Low-alloy steels have been developed which possess satisfactory properties at low temperatures. Nickel is often used in these materials and may be present in amounts up to 10 per cent.

Steels for Elevated Temperature Service—In contrast to the devices which operate at low temperature, we also have many which operate at elevated temperature, to mention a few: steam superheaters, chemical processing retorts, and oil refining towers. Unfortunately, another shortcoming of plain-carbon steel is that its strength decreases rapidly as temperature increases. A large variety of low-alloy steels are available which possess good strength at elevated temperature, that is, up to possibly 1000° F. Some of the more simple materials contain only small additions of chromium or molybdenum. The more complex materials contain additions of nickel, chromium, molybdenum, etc. In some cases the chromium may reach 10 per cent.

Stainless Steel

Stainless steels are defined as materials with unusual ability to resist attack by corrosive media at atmospheric or elevated temperatures. This unusual resistance to attack is due primarily to the chromium they contain, which in present-day "true" stainless steels generally amounts to at least 10 per cent. Nickel is also used in substantial quantities in some stainless steels. As a result, stainless steels may be grouped into two main varieties: plain-chromium and chromium-nickel. Approximately thirty grades are considered standard, but many special grades are regularly produced containing additions of elements like columbium, titanium, molybdenum, and selenium or sulphur.

High-Strength Heat-Resisting Steels

In the past six or seven years, we have witnessed the rapid development of the gas turbine—a machine closely akin to the steam turbine, but which employs hot gases of combustion for power instead of steam. The gas turbine is now working in many different forms: the aircraft turbo-supercharger, the aircraft jet propulsion unit, and as a turbine-generator for driving ships, locomotives, and so forth. The heart of each turbine, regardless of design, is the bladed rotor which is driven by the hot gases. Roughly speaking, the working efficiency of the gas turbine increases as the operating temperature rises. To secure just passable efficiency, the turbine must operate with a gas temperature in the range of 1000° to 1300° F. Turbines are being designed at the present time to operate in the range of 1300° to 1500° F. Notwithstanding, some designers are already asking for metals which will permit the gas turbine to be operated above 1500° F. The metallurgist has responded with a galaxy of alloys to be used in making combustion chambers, gas nozzles, turbine wheels, turbine blades, and piping. The simplest of these materials are the stainless steel grades, or at least modifications of the familiar grades. However, some of the materials are so highly alloyed with cobalt, molybdenum, tungsten, columbium, and titanium that they cannot be hot forged or rolled, and therefore must be employed as castings. In some cases, the iron content of the earlier materials has been replaced with nickel or cobalt so that the material cannot rightfully be called a *steel*. For lack of a better name, we have taken to calling these materials *super-alloys*. Nevertheless, the designer looks to welding as the best means of joining turbine parts regardless of the composition of the alloys, and so it falls our lot to learn how to weld these complex materials.

Tool Steel

Any steel which is employed in accomplishing a cutting or forming operation on a material might be considered a tool steel. However, we do recognize a family of steels which are manufactured specifically for making tools. While these steels may range from plain-carbon to highly alloyed material, they are always manufactured with the best mill practice in order to secure high-quality steel. The need for tool steels of many different compositions is obvious when one considers that the term *tools* covers cutting tools, punches, shear blades, dies for forming, drawing, extruding, forging, rolling, etc. We might also consider further that any one of these tools may be used on either hard or soft material, and that the material could be either hot or cold. For our purpose, the family of tool steels can be considered as consisting of four parts; (1) plain-carbon steels which contain about 0.60 to 1.5 per cent carbon for securing hardness; (2) low-alloy steels, which besides this high-carbon content, contain moderate additions of manganese, chromium, molybdenum, and vanadium to improve toughness and depth of hardening; (3) high-speed steels which contain high-carbon contents and large additions of chromium, tungsten, and molybdenum; and (4) hot work steels which generally have low-carbon content, but are highly alloyed with tungsten, chromium, vanadium, molybdenum, and cobalt.

MATERIAL SPECIFICATIONS

While catchy trade names for steel may have a more familiar ring to the ear, the various types and grades of steel are most often referred to by specification numbers. Specifications are issued by steel producers, consumers, warehousing agents, technical societies, governmental bureaus, committees, associations, etc. The problem of keeping up with the new grades of steel grows more difficult with each passing year, for as each new grade is established, it may be included in the specifications of one to a dozen agencies and identified by their own particular system of designation. The duplication of effort is tremendous. Fortunately a number of organizations have appointed committees to study the feasibility of consolidating specifications and codes to simplify the picture.

The simplest kind of specification is that which only states the composition requirements of the material. Sometimes in lieu of composition, simple mechanical properties like tensile strength, ductility, or hardness may be used. On the other hand, specifications can go to great length to state exactly what is required of the material from every standpoint of possible importance. Besides composition and mechanical properties, a specification may state requirements for hardenability, weldability, grain size, cleanliness, soundness, magnetic properties, and corrosion resistance. Often the specification will contain detailed information on the test procedure to be followed in evaluating these special requirements.

Some of the more widely used specifications are probably the following:

SAE Steel Specifications—These specifications cover only chemical composition and are very widely used in ordering steel for automotive, aircraft, and machinery applications. They were first issued by the Society of Automotive Engineers in the year 1912 and have been

Index for SAE Steel Specification Numbers

Type of Steel	SAE Number
Carbon Steels, plain and free-cutting	1XXX
Manganese Steels	13XX
Nickel Steels	2XXX
Nickel-Chromium Steels	3XXX
Molybdenum Steels	4XXX
Chromium Steels	5XXX
Chromium-Vanadium Steels	6XXX
Silicon-Manganese Steels	9XXX
Corrosion and Heat-Resisting (Cr-Ni)	30XXX
Corrosion and Heat-Resisting (Plain-Cr)	51XXX

maintained in excellent working order by periodic revisions. The SAE grades range from plain-carbon to low-alloy steels, and also include a few heat-resisting steels. The latest index system provides a four-digit number for each grade; the first two digits indicate the alloy combination, and the last two the approximate mean of the carbon range. A range of carbon contents is available for practically every alloy combination.

AISI Standard Steel Compositions—The American Iron and Steel Institute has collaborated with the SAE in issuing a new set of steel specifications which is based on the SAE grades, but which differs in two respects: first, the number of grades has been increased, and second, a code of prefix and suffix letters has been established as described below:

AISI Steel Grade Designations

Prefix Letters	Meaning
A	Basic Open-hearth Alloy Steel
B	Acid Bessemer Carbon Steel
C	Basic Open-hearth Carbon Steel
D	Acid Open-hearth Carbon Steel
E	Electric Furnace Steel
Q	Forging Quality, or Special Requirements
R	Re-rolling Quality Billets
Suffix Letters	**Meaning**
A	Restricted Chemical Composition
B	Bearing Steel Quality
C	Guaranteed Segregation Limits
D	Specified Discard
E	Macro-Etch Tests
F	Rifle Barrel Quality
G	Limited Austenitic Grain Size
H	Guaranteed Hardenability
I	Non-metallic Inclusions Requirements
J	Fracture Test
T	Extensometer Test
V	Aircraft Quality or Magnaflux Testing

These prefix and suffix letters are used in conjunction with a four-digit AISI grade number. The grade numbers are similar to, but not identical with the SAE grade numbers.

NE Steels—During World War II the WPB promulgated a number of low-alloy steel compositions to replace more highly alloyed steels and thus conserve our alloy stockpile. The performance of these National Emergency Steels in some cases was superior to their more costly predecessors and therefore some of the NE steels are still being produced today. The grades of material were as follows:

Index for NE Steel Specifications

NE 13XX	Manganese Steels
NE 8XXX	Manganese-Molybdenum Steels
NE 86XX	0.50% Ni, 0.50% Cr, 0.20% Mo Steels
NE 87XX	0.50% Ni, 0.50% Cr, 0.25% Mo Steels
NE 89XX	0.50% Ni, 0.50% Cr, 0.35% Mo Steels
NE 92XX	Silicon-Manganese Steels
NE 94XX	0.40% Ni, 0.40% Cr, 0.10% Mo Steels
NE 97XX	0.65% Ni, 0.15% Cr, 0.20% Mo Steels
NE 98XX	1.00% Ni, 0.80% Cr, 0.25% Mo Steels
NE 99XX	1.20% Ni, 0.50% Cr, 0.25% Mo Steels

ASTM Material Specifications—The American Society for Testing Materials issues specifications covering many kinds of materials which are classified and identified as follows:

A. Ferrous Metals
B. Non-Ferrous Metals
C. Cementitious, Ceramic, Concrete, and Masonry Materials
D. Miscellaneous Materials
E. Miscellaneous Subjects

The ASTM specifications are identified first by a letter indicating the class of material, then by an index number, and following a dash are two digits signifying the year of final adoption or last revision. For example, ASTM A 7–46 covers Steel for Bridges and Buildings and is the specification formally adopted in the year 1946. A suffix letter T marks a tentative specification. In general, the specifications are very thorough and include requirements for chemical composition, mechanical properties, testing procedure, inspection, and so forth.

AWS Codes and Specifications—The codes and standards issued by the AMERICAN WELDING SOCIETY are classified as shown below. A few of the more frequently used publications in each classification are listed.

A. Fundamentals of Welding

A2.0-47	Standard Welding Symbols
A3.0-42	Definitions of Welding Terms and Master Chart of Welding Processes
A4.0-42	Standard Methods for Mechanical Testing of Welds
A5.1-48T	Specifications for Mild Steel Arc-Welding Electrodes (Tentative)
A5.2-46T	Specifications for Iron and Steel Gas-Welding Rods (Tentative)
A5.3-43T	Specifications for Aluminum and Aluminum Alloy Metal Arc-Welding Electrodes (Tentative)
A5.4-48T	Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes (Tentative)
A5.5-48T	Specifications for Low-Alloy Steel Arc-Welding Electrodes (Tentative)
A5.6-48T	Specifications for Copper and Copper-Alloy Metal
B3.0-41T	Standard Qualification Procedure (Tentative)

B. Training, Inspection, and Control

B1.1-45	Inspection Handbook for Manual Metal-Arc Welding (Emergency Standard)
B3.0-41T	Standard Qualification Procedure (Tentative)

C. Processes

C1.1-46T	Recommended Practices for Resistance Welding (Tentative)
C1.2-42T	Tentative Standards and Recommended Practices for Spot Welding Aluminum Alloys (Emergency Standard)

D. Industrial Applications

D1.0-46	Standard Code for Arc and Gas Welding in Building Construction
D2.0-46	Standard Specifications for Welded Highway and Railway Bridges
D3.3-48	Rules for Welding Piping in Marine Construction
D5.1-47	Rules for Field Welding of Steel Storage Tanks

Perhaps the best known standard of the AWS is A5.1-48T, *Specifications for Mild Steel Arc-Welding Electrodes*. The system of electrode classification employed in this specification was developed in cooperation with the American Society for Testing Materials (ASTM A 233–48T) and has become widely used. The familiar *E* numbers can be found on practically every box of electrodes regardless of manufacture. The specification is chiefly concerned with usability of electrodes and the mechanical properties of the deposited weld metal. The composition of the weld metal is left largely to the judgment of the electrode manufacturer.

STEELS SUITABLE FOR WELDING

In concluding this discussion on the grades of base metals and weld metals, we will exemplify general principles by listing the steels that are acknowledged to be suitable for welding by major specification organizations.

By "suitable for welding" is meant that the steel can be welded satisfactorily by well-known techniques in the forms and for the applications that the specification for the steel describes. It is not implied that other steels not mentioned in the specifications may not be equally suitable. As a matter of fact, there are hundreds of steels, if not all steels, that are suitable for welding if due consideration is paid to the welding technique and to the properties desired in the welded structure. Only some of the steels standardized by the AWS, ASTM and the ASME Boiler Code Committee will be discussed in the following paragraphs.

The compositions that are specified refer to either the analysis of the steel in the ladle before teeming into ingots, or to the analysis of the steel in the form (plates, bars, beams, etc.) in which it is to be welded. Analyses of the latter type of products are called *check analyses*, samples for which are taken at any point midway between outside and center of the section by drilling parallel to the rolled surface. In thin material the sample may be taken across the entire cross section. The check analysis may not be the same as the ladle analysis, because for one thing the elements segregate in the ingot. Consequently, wider limits are allowed in the check analysis than in the ladle analysis.

The permissible limits within which the elements may vary are not necessarily the limits within which they will vary in practice. For example, the carbon content of *High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels* (ASTM A 212–46) may be anything up to 0.31 per cent for Grade B steel. Obviously the carbon content would never be so low as 0.05 per cent although it would be permissible, because the tensile strength requirement of 70,000 psi minimum never could be attained in thick hot-rolled plates of that carbon content. The permissible limits of strength likewise may not represent necessarily the limits within which they will vary in practice. Again as an example, the minimum tensile strength of *Corrosion-Resisting Chromium-Nickel Steel Sheet, Strip, and Plate* is given by ASTM A 167–44 as 75,000 psi. Yet Grade 10 steel in the specification (25 Cr–20 Ni) would never be expected to fall below about 90,000 psi in practice. The minimum tensile strength is specified simply as a safeguard against metal that is obviously defective mechanically while meeting the more important specified chemical composition which controls the corrosion resistance. Often an upper as well as a lower limit is placed on tensile strength to prevent the use of metal of excessively high-tensile strength, which may imply poor service characteristics despite satisfactory ductility in the tensile test of a machined bar.

The selection of limits within which the composition and properties of welding steel must fall is governed primarily by the requirements of service and fabrication; nevertheless, so far as possible the steel manufacturer is relieved of all unnecessary burden. One of the greatest burdens placed upon steel manufacturers in specifications for welding steels is low-carbon content. Production of steels with low-carbon content involves long refining times and high temperatures, both of which reduce the life of the furnace linings and increase the difficulty of eliminating slag inclusions. Besides composition and tensile strength, the yield point and ductility of the steel in the tensile test are specified for welding steels and they must pass a bend test and a homogeneity test to demonstrate satisfactory forming qualities and absence of laminations. It is difficult to produce a rimming steel that will pass the homogeneity test consistently; no alloy steel will be manufactured by the rimming process. Nevertheless, plain-carbon steel plates and structural products containing 0.15–0.25% C often are made of semi-killed steel, which is the process intermediate between rimming (no silicon) and killing with silicon. Low-carbon steel sheets (0.05–0.15% C) generally are made of rimming steel.

A particularly important class of steel is that which is used for boilers and other pressure vessels. Welding is employed almost exclusively for joints in these vessels for steam power, refinery and chemical purposes having wall thicknesses up to 6 inches or more. A number of typical ASTM and ASME Boiler Code Specifications are presented in the concluding paragraphs of this chapter.

Several items may be commented upon. Stricter requirements are placed upon firebox-quality than upon flange-quality plate. The maximum permissible carbon is higher for thick plates than for thin, although we shall see later that hard zones which form adjacent to a weld are favored by increase in both thickness and carbon content. Ideally we should wish the carbon content to be lower in the thicker plates than in the thin to avoid these hard zones. However, to meet strength requirements the steel manufacturer must be permitted to supply higher carbon content in the thicker plate which cools more slowly because of its mass and tends to be softer and lower in tensile strength. The higher phosphorus content permitted in steels made in acid (sand or silica lined) furnaces than in basic-lined furnaces reflects the inability of the acid process to remove phosphorus from the charge, which must therefore be of a lower phosphorus content (signifying better quality in general) than in the basic process. This specification and nearly all others for these steels also require that plates over 2 inches thick be uniformly heat treated to refine the grain size before fabrication and welding. The heat-treating operation may involve normalizing (a treatment described in Chapter 11) which improves particularly the ability of thick plates to be formed to shape, and also improves the ability of the steel after welding to resist propagation of a crack under stress.

A 285–46 Low and Intermediate Tensile Strength Carbon Steel Plates of Flange and Firebox Qualities

Firebox Quality	Grade A	Grade B	Grade C
Carbon, max. percent			
¾ in. and under	0.15	0.20	0.25
Over ¾ in. to 2 in.	0.17	0.22	0.30
Mn, max percent	0.80	0.80	0.80
P, max. percent acid	0.04	0.04	0.04
P, max. percent basic	0.035	0.035	0.035
S, max. percent	0.04	0.04	0.04
Tensile Strength, 1000 psi	45–55	50–60	55–65
Yield Point, min. psi	0.5 TS	0.5 TS	0.5 TS
But not less than 1000 psi	24	27	30
Elongation in 8 in., min. percent	1,500,000 TS	1,500,000 TS	1,500,000 TS
Flange Quality	**Grade A**	**Grade B**	**Grade C**
Carbon, max. percent			
¾ in. and under	..	..	..
Over ¾ in. to 2 in.	..	..	..
Mn, max. percent	0.80	0.80	0.80
P, max. percent acid	0.06	0.06	0.06
P, max. percent basic	0.04	0.04	0.04
S, max. percent	0.05	0.05	0.05
Tensile Strength, 1000 psi	45–55	50–60	55–65
Yield Point, min. psi	0.5 TS	0.5 TS	0.5 TS
But not less than 1000 psi	24	27	30
Elongation in 8 in., min. percent	1,500,000 TS	1,500,000 TS	1,500,000 TS

In contrast with A 285–46, a silicon content of 0.15–0.30 per cent is specified in A 201–46 in order to limit the carbon content to the lowest practicable amount consistent with the specified thickness and tensile strength. The permissible phosphorus and sulphur contents of flange and firebox qualities are so closely the same in A

201–46 and other specifications as in A 285–46 that they are not repeated. Notice that the required minimum elongation value is determined by dividing a number in the neighborhood of one and one-half million by the tensile strength value.

A 201–46 Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (Boiler Code Specification No. SA-201)

	Grade A	Grade B
Carbon, max. percent		
1 in. and under	0.20	0.24
Over 1 in. to 2 in.	0.24	0.27
Over 2 in. to 4 in.	0.27	0.30
Over 4 in. to 6 in.	0.31	0.35
Over 6 in. to 12 in.	0.35	..
Mn, max. percent	0.80	0.80
Si, percent	0.15–0.30	0.15–0.30
Tensile Strength, 1000 psi	55–65	60–70
Yield Point, min.	0.5 TS	0.5 TS
Elongation in 8 inches, min. percent		
Flange	1,500,000 / TS	1,500,000 / TS
Firebox	1,550,000 / TS	1,550,000 / TS

A 212–46 High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels

	Grade A	Grade B
Carbon, max. percent 1 in. and under	0.28	0.31
Over 1 in. to 2 in.	0.31	0.33
Over 2 in. to 4½ in.	0.33	0.35
Mn, max. percent	0.90	0.90
Si, percent	0.15–0.30	0.15–0.30
Tensile Strength, 1000 psi	65–77	70–82
Yield Point, min.	0.5 TS	0.5 TS

The higher strength in A 212–46 compared with A 201–46 is secured by higher carbon and manganese contents.

Two types of alloy steels frequently used for welded pressure vessels are described in Specifications A 204–46 and A 225–46 shown below.

A 204–46 Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (Suitable for Welding) (Boiler Code Specification No. SA-204)

	Grade A	Grade B	Grade C
Carbon, max. percent			
1 in. and under	0.18	0.20	0.23
Over 1 to 2 in.	0.21	0.23	0.26
Over 2 to 4 in.	0.23	0.25	0.28
Over 4 to 6 in.	0.25	0.27	..
Mn, max. percent	0.90	0.90	0.90
Si, percent	0.15–0.30	0.15–0.30	0.15–0.30
Mo, percent	0.40–0.60	0.40–0.60	0.40–0.60
Tensile Strength, 1000 psi	65–77	70–82	75–87
Yield Point, min.	0.55 TS	0.55 TS	0.55 TS

A 225–46 Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (Suitable for Welding)

	Grade A	Grade B
Carbon, max. percent	0.18	0.20
Mn, max. percent	1.45	1.45
Si, percent	0.15–0.30	0.15–0.30
V, percent	0.08–0.14	0.08–0.14
Tensile Strength, 1000 psi	70–82	75–87
Yield Point, min.	0.55 TS	0.55 TS

In the interests of good forge welding, limitations are placed upon the silicon, nickel, and chromium contents. Each of these elements is generally held to a maximum of 0.08 per cent. Copper is also held low, usually to 0.15 percent maximum. Nevertheless, nickel steels have been forge welded in production.

Several ASTM specifications deal with steel castings suitable for fusion welding. Specification A 27–46T lists eight grades of plain-carbon cast steel with 0.25% C max. or 0.35% C max., 0.50% Si max., 0.60%, 0.70% 0.75%, or 1.00% Mn max., 0.06% S max., and 0.05% P max. The minimum tensile strength requirements for these grades vary with the carbon content. Before they are welded, all castings must be normalized or full annealed. The object of heat treatment is to relieve shrinkage stresses due to casting and to refine the cast structure of the steel. In this way welding is performed on the steel in its strongest and most ductile condition.

Often, without adequate reason, steel castings are said to be more difficult to weld than wrought steel. It is true that the carbon content of steel castings generally is rather high from the welding viewpoint, 0.20 per cent or higher, combined with higher manganese and silicon contents than will be found in wrought plain-carbon steel. The high manganese and silicon contents of steel castings are necessary for satisfactory deoxidation. Substitution of alloying elements for carbon is said to decrease cracking difficulties. The welding operator must allow also for the complicated shape of many steel castings. If, in the cast steel frame in Figure 7, parts are welded simultaneously at *A* and *B*, the expansion of the end members may seriously strain the center strut or may start cracks at the sharp corners. Had the casting been of gray cast iron instead of cast steel, any welding at *A* and *B* would be expected to crack the center strut. Gray cast iron, which contains 3 to 3½ percent carbon, is entirely different from cast steel. The former exhibits practically zero elongation at fracture in the tensile test, whereas the ductility of cast steel compares favorably with that of wrought steel. Since cast steel is subject on a large scale to the shrinkage cavities, porosity and hot cracks that sometimes afflict welds, repairs to steel castings should not be attempted until chipping has reached perfectly sound metal. Cracks may spread during welding from the slightest defect that is not removed beforehand.

Fig. 7—Frame with Attachments Welded at A and B

SUGGESTED READING

Basic Open Hearth Steelmaking, 1944, Physical Chemistry of Steelmaking Committee, Iron and Steel Division, American Institute of Mining and Metallurgical Engineers.

The Making, Shaping and Treating of Steel, by J. M. Camp and C. B. Francis, 1940, Carnegie-Illinois Steel Company, Pittsburgh, Pa.

Iron and Steel, by H. M. Boylston, 1936, John Wiley and Sons, Inc., New York, N. Y.

The Manufacture of Electric Steel, by F. T. Sisco, 1924, McGraw-Hill Publishing Company, New York, N. Y.

Three-Phase, Direct-Energy, Resistance-Welding Equipment

The advantages of dry-disk rectifier or d.-c. welders as judged by welder power and welding current characteristics predominate over the advantages of low-frequency welders

by J. H. Cooper

INTRODUCTION

THE scope of this paper is restricted to direct energy systems and thus involves no discussion of the well-known types of stored energy systems.

It is further restricted to three-phase systems and therefore does not include the most commonly used single-phase direct-energy welders.

It excludes other direct-energy types, such as the seldom used three-phase motor generator set and three-phase "scott" connected transformer arrangement. It thus includes only (*a*) Three-phase, full-wave, dry-disk rectifier or d.-c. welders and (*b*) Three-phase, half-wave, electronic frequency-converter or low-frequency welders.

A number of papers have been written (see bibliography) and much discussion has taken place on the design features of these two types of resistance-welding systems. It is the intent of this article to avoid as much as possible, because of space limitations, any reference to the design features other than a short description of each to thoroughly identify the underlying principles of each.

After the short identifying description of each system, let us assume, for purposes of this discussion, that the welder is a "mysterious black box" to which we connect a three-phase power supply and from which we extract welding current in the form of d. c. or low frequency. Such an assumption will be most convenient as it will avoid highly technical factors upon which even well-informed design engineers may disagree and thus permit us to use uncomplicated language in describing welder performance. The better and faster we can produce welds, the smaller the disturbance to the power supply system, the broader the range of ferrous and nonferrous materials, as well as thicknesses covered by one unit, the less we have to open up the "box" to maintain the equipment and the lower the cost of replacement parts when this is necessary, the higher the degree of satisfaction to all parties.

J. H. Cooper is connected with The Taylor-Winfield Corp., Warren, Ohio.

Paper presented at the Western Metal Congress and Exposition, Los Angeles, Calif., April 1949.

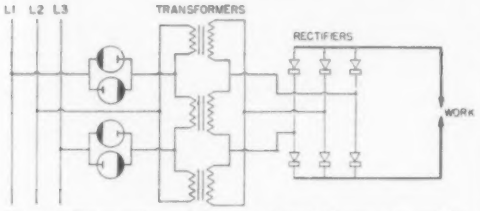


Fig. 1 Three-phase, full-wave, dry-disk rectifier welder

THREE-PHASE, FULL-WAVE, DRY-DISK RECTIFIER OR D.-C. WELDERS

Reference to the schematic diagram, Fig. 1, indicates the use of a three-phase transformer system which feeds a low-voltage high-current a. c. output into a rectifier power pack which in turn acts like electrical check valves to provide d.-c. welding current to the work. The transformer primaries are connected to or disconnected from the power supply by contactors (usually electronic) to turn the welding current off or turn it on as long as the weld requires it. The welding transformers are of conventional construction with primary windings to operate on various power supply voltages and frequencies. The rectifiers consist of a group of heavy copper plates, like bus bars, between which are assembled the rectifying disk assemblies. These disk assemblies are of the magnesium-copper-sulphide type, which type has the ideal characteristics for welder service of operating at high currents; withstanding heavy overloads; self-healing rectifying layer if accidently punctured, etc. Figure 2 shows a typical rectifier stack and Fig. 3 a typical transformer and rectifier power pack which replaces the conventional single-phase transformer in a welder. Figure 4 shows the typical a.-c. primary and d.-c. secondary current traces of a three-phase full-wave rectifier welder. Note continuous nature of all traces. The shape, length and amplitude of the d.-c. wave will vary with different applications.

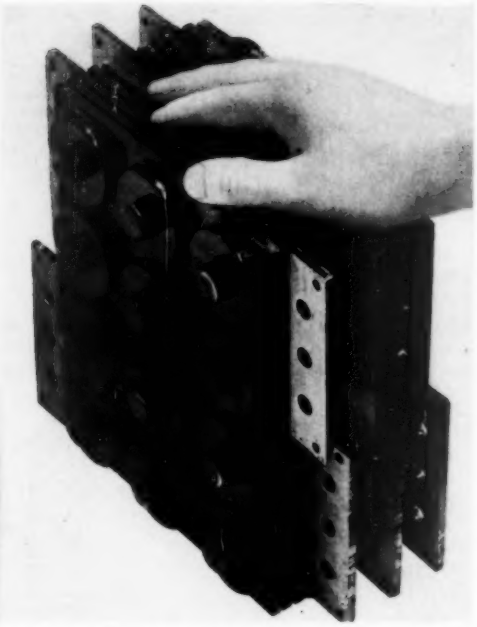


Fig. 2 Magnesium-copper-sulphide rectifier stack

THREE-PHASE, HALF-WAVE, ELECTRONIC FREQUENCY-CONVERTER OR LOW-FREQUENCY WELDERS

Reference to the schematic diagram, Fig. 5, indicates the use of a transformer which has three primary windings on one core and one single-phase secondary winding, which secondary winding is connected to the welder conductors. The transformer primary windings are connected to the power supply by three electronic contactors. Electronic tubes *A1*, *A2* and *A3* first pass pulsating current in the same direction through the three primary windings and then these tubes stop firing and, after a switching interval, tubes *B1*, *B2* and *B3* pass pulsating current of opposite polarity through the same windings. The duration of these impulses of alternating polarity is limited by saturation of the transformer iron and the transformer is necessarily larger than an equivalent 60-cycle transformer. The frequency of the impulses is usually established at about 12 cps. This means each impulse is approximately $2^1/_2$ cycles of 60-cycle secondary frequency in length. An interval of about $^1/_3$ cycle is often provided between impulses to provide for electronic switching of the power-tube groups.

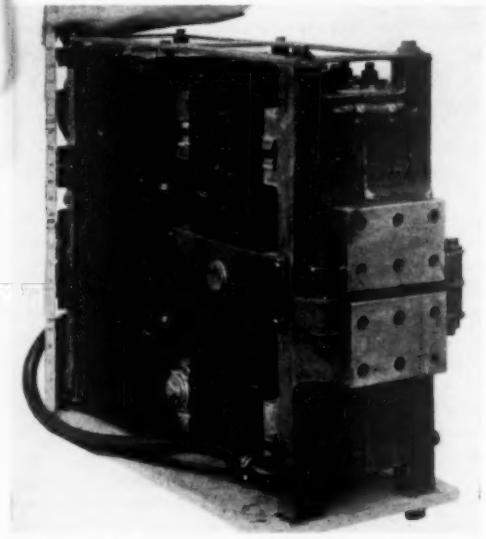


Fig. 3 Tri-phase power pack (Mg-Cu-S rectifiers)

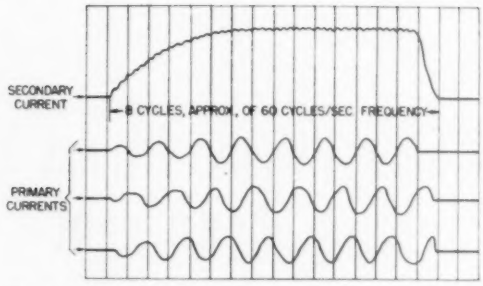


Fig. 4 Primary and secondary currents of a typical three-phase, full-wave, dry-disk rectifier welder

Sometimes the low-output frequency is adjustable slightly from the 12 cps., but to go to lower frequencies requires more transformer iron and to go to higher frequencies involves higher power-line demand. The selection of 12 cps. is a convenient compromise between these two alternatives. The $2^1/_2$-cycle (60 cps.) impulses can be repeated as long as is necessary to make the weld.

Figure 6 shows the typical a.-c. primary and low-frequency secondary current traces of a three-phase, half-wave, frequency-converter welder when making a two-impulse weld. Note the discontinuous nature of all traces. The shape and amplitude of the low-frequency pulses will vary with different applications.

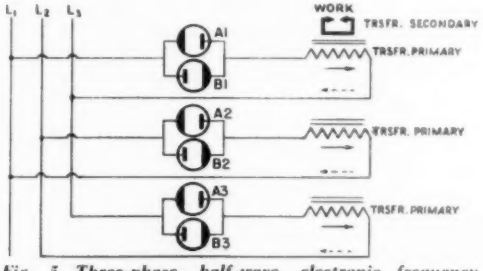


Fig. 5 Three-phase, half-wave, electronic frequency conversion system

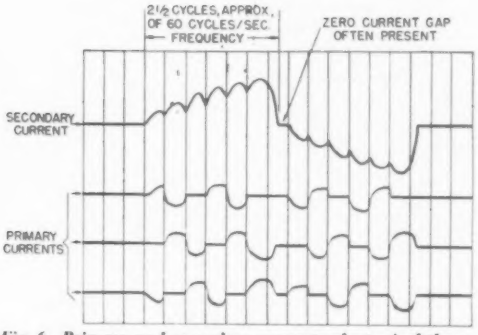


Fig. 6 Primary and secondary currents of a typical three-phase, half-wave, frequency-converter welder

WELDER POWER CHARACTERISTICS

Four yardsticks can be used to judge the electrical effect of a welder on a power supply line, listed as follows:

(*a*) Minimum possible total power demand
(*b*) Maximum possible power factor
(*c*) Highest degree of balance of power demand on all three phases
(*d*) Avoidance of the zone of highest sensitivity to objectionable light flicker.

In regard to the first two factors, minimum possible total demand and maximum possible power factor are directly related when producing the same welding current. As the power factor increases, the total kilovolt-ampere demand decreases until the total demand is at the lowest possible value when the power factor is 100%. Many 60-cycle resistance welders have power factors as low as 20 to 35%, so that much opportunity exists for the reduction of total demand.

The power factor increases and the demand decreases as the frequency of the welding current decreases. Half-wave, electronic frequency-converter welders producing welding currents of approximately 12 cycles per second are a step in the right direction for the reduction of power demand. Three-phase, full-wave, dry-disk rectifier welders producing d.-c. welding current (zero frequency) reduce power demand to an even greater degree. The degree of reduction in all cases will depend upon the welder characteristics on a 60-cycle power supply and also upon design efficiency, but an example of the power reduction of both systems operating under comparable conditions is given in Fig. 7. These curves show, for example, that the total three-phase power demand of a 24-in. throat depth, Size 3, press welder of the rectifier type will be 28.5% of the single-phase power demand of a single-phase welder producing the same welding current. Under comparable conditions, the total three-phase power demand of a frequency-converter welder will be 33% of the single-phase welder demand. A comparison of the line demand of each of the three phases of a three-phase welder of either type with the demand of a single-phase welder would be even more favorable to three-phase welders. The lowest demand and highest power factor will keep power demand charges to a minimum, as well as costs of power distribution equipment. The use of phase shifting heat control below maximum setting may increase power demand as much as 220% over that required to produce the same welding current without such type of heat control.

The effective power factor (not measurable with ordinary instruments) of a half-wave frequency-converter welder will depend upon the 60-cycle power factor but will range from 70 to 90% for 60-cycle power factors of 20 to 40%, respectively. The power factor is reduced if phase shifting heat control is used below maximum setting. A full-wave type of heat control does not have this effect on power demand and power factor.

The power factor (measurable with ordinary instruments) of a full-wave rectifier or d.-c. welder is independent of the 60-cycle power factor and is as close to 100% as can be measured with ordinary instruments. Figure 8 shows a d.-c. welding current oscillogram and a watt oscillogram taken in one phase of the three-phase supply. The watt oscillogram is a double-frequency trace with the peak deflection above zero representing true watts and the peak deflection below zero representing reactive watts. It is seen that this equipment operates at least within 1% of unity power factor, i.e., 99%, because there is essentially no deflection below zero.

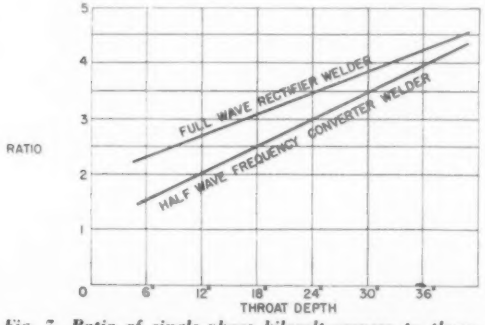


Fig. 7 Ratio of single-phase kilovolt-ampere to three-phase kva. power demand of R.W.M.A. Size 3 press welder

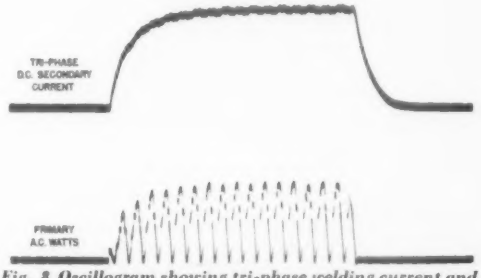


Fig. 8 Oscillogram showing tri-phase welding current and primary a.-c. watts in one of the three-phase power supply lines

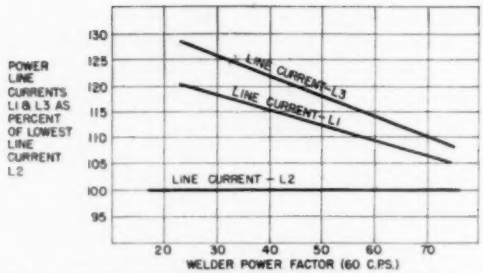


Fig. 9 Degree of unbalance of line currents of half-wave, frequency-converter welder

The third factor of balancing the total power demand equally on all three phases of the supply line is an important one. The line demand of each phase is 58% of the total three-phase demand with an equally balanced load. Balanced loading not only makes for more stable voltage conditions (better regulation) but also permits equal heating of the three-power supply lines, switches, fuses, etc. It permits measuring welder primary currents on only one phase instead of all three. Unbalanced currents require the selection of welder ignitron tubes and other equipment to carry the heaviest of the three line currents.

The degree of unbalance of line currents of this type of half-wave, frequency-converter welder is dependent upon the 60-cycle power factor of the welder. Figure 9 shows this unbalance which may be appreciable at low-power factors.

The line currents of a full-wave dry disk rectifier or d.-c. welder are equally balanced and are independent of the 60-cycle power factor. Figure 10 is an oscillogram showing balanced line currents during a typical weld, as may be measured by using a pointer-stop ammeter in each primary line.

The fourth yardstick used to judge the acceptability of a welder load on the power supply concerns whether the welder load causes sufficient change in the line voltage to create either an "objectionable light flicker" or to affect the proper operation of other electrical

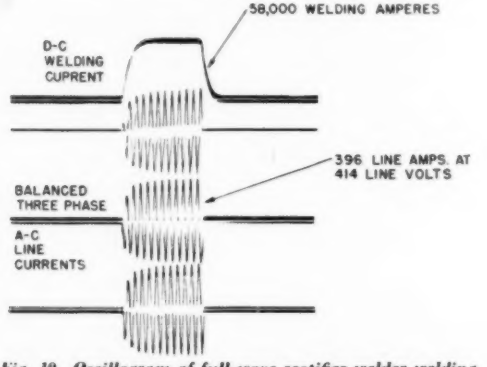


Fig. 10 Oscillogram of full-wave rectifier welder welding two thicknesses 0.102-in. 24ST Alclad and showing balanced a.-c. line currents and d.-c. welding current

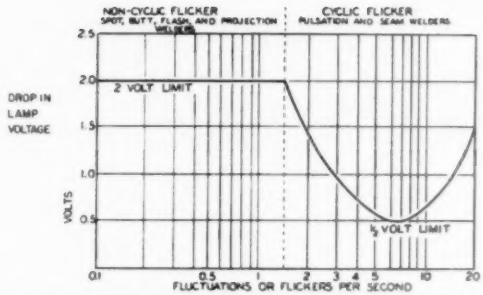


Fig. 11 Objectionable limits of light flicker caused by welder loads

equipment. Figure 11 shows how certain "flicker frequencies" cause more objection to certain voltage drops than the same drop at other frequencies. The 12-cycle frequency-converter welder is almost in the middle of the dip in the curve showing the objectionable flicker-frequency range. This unavoidable low-frequency flicker is not present in the continuous primary currents during a weld made with a rectifier or d.-c. welder (see Fig. 12).

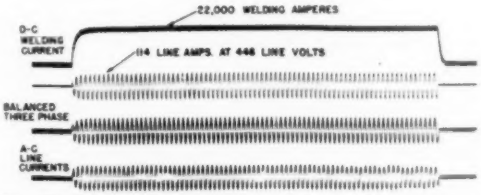


Fig. 12 Primary line currents and d.-c. welding current of 80-cycle (60 cps.) weld with rectifier welder when welding two thicknesses 3/16-in. steel

Additional factors are the "ripple frequency" and "ripple percentage." The ripple frequency of the d.-c. current of the three-phase full-wave rectifier welder is 360-cps. and is 180 cps. for the secondary current of the half-wave, frequency-converter welder. Reference to the oscillogram of the rectified d.-c. current wave in Fig. 10 shows the effect of the ripple percentage in the heaviness of the top part of the trace. Reference to the secondary current wave in the oscillogram, Fig. 18, shows the substantially greater ripple percentage for a frequency-converter welder. This oscillogram was taken operating at 100% heat control and when phase-shifting heat control is reduced, the ripple becomes appreciably deeper and the ripple percentage increases.

WELDING CURRENT CHARACTERISTICS

Seven yardsticks can be used to judge the desirability of welding current produced by these three-phase welders, listed as follows:

(*a*) Flexibility and precision of timing.

Heat time		Cool time	
Cycles, 60 cps.*	Milliseconds†	Cycles, 60 cps.	Milliseconds
1.14	19	0.84	14
2.28	38	1.68	28
3.42	57	2.52	42
4.56	76	3.36	56
5.70	95	4.20	70
6.84	114	5.04	84
7.98	133	5.88	98
9.12	152	6.72	112
10.26	171	7.56	126
11.40	190	8.40	140
12.54	209	9.24	154
13.68	228	10.08	168
14.82	247	10.92	182
15.96	266	11.76	196
17.10	285	12.60	210
18.24	304	13.44	224
19.38	323	14.28	238
20.52	342	15.12	252
21.66	361	15.96	266
22.80	380	16.80	280
23.94	399	17.64	294
25.08	418	18.48	308
26.22	437	19.32	322
27.36	456	20.16	336
28.50	475	21.00	350
29.64	494	21.84	364
30.78	513	22.68	378
31.92	532	23.52	392
33.06	551	24.36	406
34.20	570	25.20	420
35.34	589	26.04	434
36.48	608	26.88	448

* Cycles (60 cps.) = 0.06 millisecs.
† Milliseconds = cycles (60 cps.) × 100/6.

Fig. 13 Timing chart for precision type of control for rectifier seam, spot or projection welder

(*b*) Continuity of heat input.
(*c*) Most desirable wave shape.
(*d*) Self-regulating characteristic.
(*e*) Minimum inductive effect on welding current by variation in throat area and by presence of magnetic work and fixture materials.
(*f*) Polarity effect of welding current.
(*g*) Ease of measurement of welding current.

In regard to the flexibility of timing, the first and most important requirement of the welding current is that the timing can be precisely adjusted to any schedule that the weld needs. Low-frequency welders and d.-c. welders radically differ in the degree of flexibility of timing available. Reference to Figs. 6 and 18 shows that the minimum time available using a three-phase, half-wave frequency-converter welder of the 12-cycle welding current type is approximately 2½ cycles (60 cps.), or 41 millisec. Minor variations from the 12-cycle frequency still retain approximately the same minimum welding time. This is an undesirably long welding time when making high-quality welds in relatively thin aluminum and other applications requiring shorter time. Arrangements to reduce this minimum time result in either increasing power demand and reducing power factor progressively as the frequency is raised until the 60-cycle frequency is reached or else result in a single-phase weld with its possible disadvantages.

Other welding times than the minimum must be adjusted in approximately 2½ cycle (60 cps.), 41 millisec., steps for 12-cycle, frequency-converter welders or similar steps for other low frequencies. It is not possible to have continuous timing without these 2½-cycle pulsations nor is it possible to obtain one continuous pulse of the required length to weld the heavier thicknesses of aluminum and other nonferrous materials most efficiently.

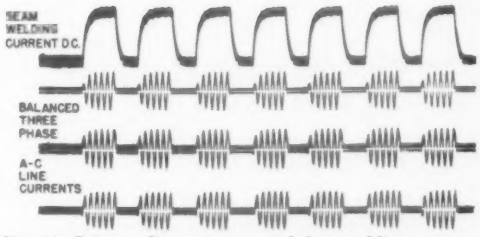


Fig. 14 Primary line currents and d.-c. welding current of three-phase rectifier seam welder

The d.-c. welding current of the rectifier welder can be turned on and off to suit the exact requirements of the work with no inherent limitations due to the welding current wave. Figures 10 and 12 show continuous spot welding times of 11 and 80 cycles (60 cps.), respectively. Figure 14 shows the oscillographic traces of a seam weld with a timing schedule of 5 cycles on and 4 cycles off (60 cps.).

Due to the nature of the three-phase power supply, see Fig. 15, the three-phase equivalent of a single-phase synchronous-precision timer does not permit measuring out welding time in integral cycles of 60-cps. frequency. The use of the term "milliseconds" as a measurement of weld time of a three-phase welder is correct, whereas "cycles" is not. The precisely accurate steps of timing in such a timer are 19 millisec. and not 16.7 millisec. (1 cycle). Figure 13 shows the timing range of such a precision timer for a seam or pulsation welder of the rectifier or d.-c. type. Note that adjustment of heat time can be made over a range of 1 to 36 cycles, 19 to 608 millisec., in approximately 1-cycle steps. A

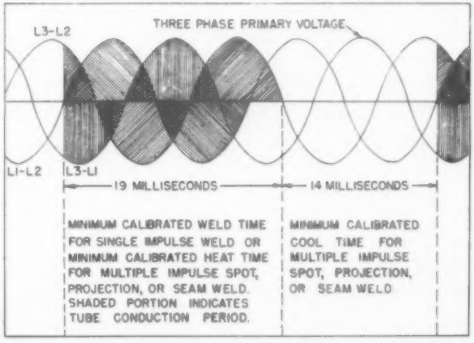

THREE PHASE PRIMARY VOLTAGE
L3-L2
L1-L2
L3-L1
19 MILLISECONDS
14 MILLISECONDS
MINIMUM CALIBRATED WELD TIME FOR SINGLE IMPULSE WELD OR MINIMUM CALIBRATED HEAT TIME FOR MULTIPLE IMPULSE SPOT, PROJECTION, OR SEAM WELD. SHADED PORTION INDICATES TUBE CONDUCTION PERIOD.
MINIMUM CALIBRATED COOL TIME FOR MULTIPLE IMPULSE SPOT, PROJECTION, OR SEAM WELD

Fig. 15 Primary voltages using precision control with rectifier spot, projection or seam welder

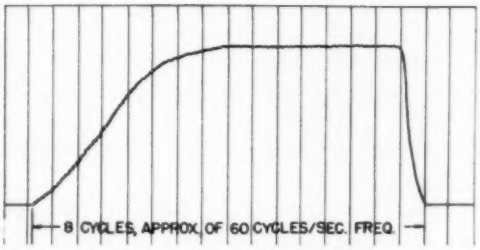


Fig. 16 Heat delivered to a weld by a typical three-phase, full-wave, dry-disk rectifier welder

similar precision timer for spot welding is adjustable over a range of 1 to 584 cycles in 1-cycle steps.

The continuity of heat input to a weld is comparable in many ways to continuity of timing. It is highly desirable to maintain continuity of heat input and alter the heat pattern as is needed by the weld and not to be restricted by limitations artificially imposed by any welding-power system. Such continuity of heat input will make some applications successful which would otherwise be unacceptable.

A good example is the continuous seam welding of steel to obtain a minimum of surface marking or a pressure-tight seam at high speeds. In one installation the d.-c. current of a rectifier welder satisfactorily replaced a 60-cycle welder which gave unacceptable results, due to the heat ripple of a 60-cycle continuous current in a weld in steel. Any lower frequency than 60 cycles would have been unthinkable.

Continuity of heat input is particularly desirable when spot or projection welding materials of high conductivity such as aluminum, where heat loss between pulses is appreciable. Reference to Figs. 16 and 17 shows the pattern of continuity of heat input obtained from the d.-c. welding current of a rectifier welder and from the 12-cycle, low-frequency welding current of a frequency-converter welder. These heat patterns are not made under comparable welding conditions, but show continuity or lack of continuity of heat flow. The d.-c. heat level can be sustained as long as needed by the weld, but the heat level of the low-frequency current is broken up by gaps of $2^1/_2$ cycles (60 cps.) from peak to peak.

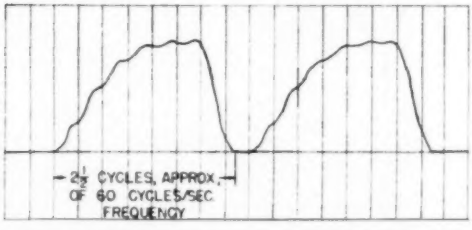


Fig. 17 Heat delivered to a weld by a typical three-phase, half-wave, frequency-converter welder

The sustained $2^1/_2$-cycle heat level of the low-frequency current is too long to acceptably weld thin aluminum.

The continuous heat flow of d.-c. welding current often increases production by shortening the welding time with no increase in peak welding current or welding force. Heat losses into the work around the weld area and resultant work warpage are minimized with the continuous d. c. because of this shorter welding time. It is desirable in many cases to keep time of heat flow to a minimum by using as short welding times as practical together with a continuous rate of heat flow to minimize heat-affected area around the weld and so minimize detrimental effects on the physical properties of the welded joint.

In connection with the wave shape of the welding current and welding heat, the terms "low-wave front" and "low rate of rise" have been the subject of much discussion in connection with three-phase welding equipment. Reference to Figs. 4, 6, 8, 10, 12, 14 and 16–19 show examples of such welding currents and welding heats.

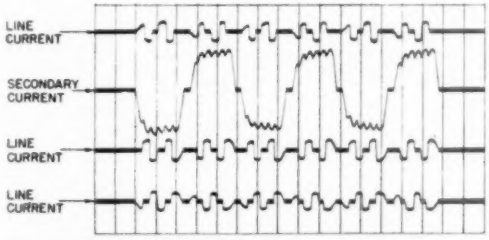


Fig. 18 Oscillograph showing primary line currents and secondary welding current of half-wave, electronic frequency-converter welder

Unfortunately and almost without exception, such discussion has either stated or left the impression that a low rate of rise of welding current is an unadulterated good characteristic and has no disadvantages whatsoever. Experienced appraisal of this low rate of rise indicates that there are many applications where it is of distinct benefit over and above the conventional 60-cycle welding current wave shape. There are, however, a few applications where a 60-cycle wave shape is preferable over a wave shape with a low rate of rise. This statement applies to both frequency-converter and rectifier or d.-c. welders.

Too much emphasis cannot be placed upon the necessity of an intelligent and experienced analysis as to whether a 60 cycle or a low rate of rise is best for each application.

Figure 19 shows a 60-cycle welding current wave with a superimposed equivalent d.-c. current wave. The shaded areas of the a.-c. wave are the important areas of difference in the two waves. The instantaneous watts of heat at the end of the first $^1/_4$ cycle of welding current is 25 times greater for the a.-c. wave than for the d.-c. wave (watts at *A* is 25 times watts at *B*).

Most welds, whether spot, seam or projection, will

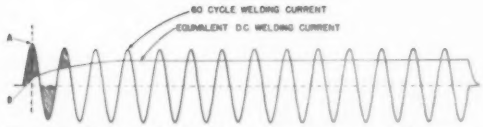


Fig. 19 Sixty-cycle welding current wave with superimposed equivalent d.-c. welding current wave for comparison

have a relatively high-contact resistance at the beginning of weld time caused either by surface roughness, shape of projection, uncleanliness of work material or electrode contact faces, etc.

In many such applications, it is advantageous to use a wave shape with a low rate of rise to restrict the peak welding heat during the initial portion of welding-current flow and to give the contact resistance between electrodes and work, as well as between the workpieces, sufficient time to be decreased without spitting out of hot metal, blowing tops off of projections, surface burning, etc. Better welding and electrode life results.

Like many good things, overdoing the matter may be detrimental to best results. If a wave has too slow rate of rise, when welding projections in thin material the projections will collapse at low heat levels and, subsequently, higher heat levels will not produce satisfactory welds. Such applications may be best done with the steeper wave front of a 60-cycle wave.

In those applications where the low rate of rise can be used, reduced welding forces can sometimes be used; the effect of projections of slightly varying height can be tolerated; welder head inertias are not so critical; work electrode burning or pickup may be reduced; and, in general, welding schedules are less critical and more flexible.

The rate of rise of the welding-current wave varies as heat is changed by use of a phase-shifting heat control, becoming steeper as heat is reduced, but does not change if the full wave type of heat control is used.

It is difficult to evaluate the benefits derived from a low rate of rise of welding current as distinct from the benefits of a high ratio of rms. to peak welding current. If is the combination of the two factors which usually produces beneficial results. In connection with this fact, it should be noted that the d.-c. current of a rectifier welder has a higher ratio of rms. to peak current than the welding currents of either 12- or 60-cycle welders.

The term "self-regulating characteristic" has been discussed often in connection with three-phase welders and merits careful consideration. It is primarily an electrical circuit characteristic but deserves attention in this discussion because it affects the amplitude and wave shape of the welding current and, therefore, affects welding results.

It is the characteristic which causes the welding current to follow changes in impedance of the work, of the rectifiers, of the contact resistance, etc. Essentially all resistance welders have it to some degree or other as they are inherently not constant current devices. In the majority of single-phase, a.-c. welders, particularly when spot or seam welding with welders of low-power factor, its effect is usually not noticed. Minor variations in work resistance have little effect on the total welder impedance or the welding current when a constant voltage is applied.

As welder power factors approach 100%, the effect becomes more noticeable (assuming the usual practice of keeping low-welder resistance) and is present in both rectifier d.-c. welders and low-frequency welders.

D.-c. welders using magnesium-copper-sulphide rectifiers have this characteristic to a greater degree than low-frequency welders, primarily because the rectifiers have an "inverse resistance characteristic" which causes the rectifier internal resistance to decrease as the current increases. This double effect of essentially 100% power factor and inverse resistance causes the self-regulating effect to be rather pronounced.

Welding benefits derived from this characteristic are:

1. Use of less sensitive welding schedules
2. Less sensitivity to changes in work thickness and electrode wear
3. Closer spot spacing

Single phase a.-c. welders require consideration, due to changes in welding current because of changes in the welder throat area or because magnetic work materials or fixtures are put into the machine or near the secondary conductors. Such current changes are undesirable and also undesirable heating may take place in the work, fixtures or machine parts.

These undesirable effects become less and less, as frequency is reduced from 60 cycles to zero, and are at a minimum when d.-c. current is used.

One investigation showed that the insertion of a specified amount of steel plate in the welder caused the current in a 60-cycle, single-phase, a.-c. welder to drop 21%, whereas comparable tests with a 12-cycle, low-frequency welder caused a current drop of 7%. This variation in welding current of 7%, which is 13.5% in heat, can be avoided by the use of d.-c. current which causes no drop in either current or heat. Compensation for this inductive effect in low-frequency welders can be made by manually changing heat settings between spots to maintain constant welding heat and does so by increasing the power demand.

Welder throat areas can be altered and welders with deeper throat depths and greater work clearances can be used where the inductive effects of any frequency are eliminated by the use of zero frequency (d. c.).

Polarity effect of the welding current sometimes may be noticed when welding certain materials in certain thicknesses. It shows up as slightly more heat in the workpiece contacted by the positive electrode usually evidenced by slightly more penetration into that piece.

This effect has long been experienced and recognized when using $^1/_2$-cycle welding time of 60- or 25-cycle frequency. It is also a characteristic of most stored

energy welders which produce a d.-c. pulse of current. It can readily be observed in certain seam welds made with frequency converter welders, inasmuch as the penetration of the weld nugget shifts back and forth in the work as the polarity is reversed. The use of a non-reversing polarity, that is, unidirectional or d.-c. current is of advantage when using positive polarity and one large electrode on one side of two workpieces of equal thicknesses, such as is so often done on the air stream side of aircratt welds in aluminum. It is thus of advantage in balancing penetration in both pieces. It is also of advantage when welding materials of unequal thicknesses and metals of dissimilar conductivity where the weld nugget can be arranged in best position for every weld.

Low-frequency currents with reversing polarity can use the polarity effect in locating the position of the weld nugget only on every other weld and the reversal acts as a disadvantage on alternative welds.

Ability to measure welding currents is an ever-present necessity for the production of high-quality welding.

The welding currents of single-phase, a.-c. welders are obtained by measuring the primary current and multiplying such values by the turns ratio of the transformer. In many applications, pointer-stop ammeters are permanently mounted on the welder with a tapped current transformer in the welder primary circuit. Modern transformer design is such that the accuracy of this method of measurement is usually limited by the accuracy of reading the ammeter and is a satisfactory and practical method.

This same method of obtaining the welding currents of a three-phase rectifier d.-c. welder through the measurement of any one of the three balanced primary currents produces satisfactory results, although it may be more convenient to directly measure the d.-c. welding current.

The measurement of the welding current of a low-frequency welder is a more difficult problem since the primary currents are not balanced, and in any case will depend upon the degree of saturation of the transformer iron and the performance of the ignitron tubes during the interval between successive current pulses. A practical method of direct measurement of the low-frequency welding current is not available, although an investigation is proceeding which may produce a current transformer satisfactory for directly measuring the high-welding currents at these low frequencies.

CONCLUSIONS

This discussion concerns only three-phase direct energy resistance welder of the dry-disk rectifier or d.-c. type and the electronic-frequency converter, or low-frequency type.

Design features are not the main point of discussion but only—(1) welder power characteristics and (2) welding current characteristics.

1. Welder power characteristics of primary interest are:

   (*a*) Minimum possible total power demand
   (*b*) Maximum possible power factor
   (*c*) Highest degree of balance of power demand on all three phases
   (*d*) Avoidance of the zone of highest sensitivity to objectionable light flicker

2. Welding current characteristics of major importance are:

   (*a*) Flexibility and precision of timing
   (*b*) Continuity of heat input
   (*c*) Most desirable wave shape
   (*d*) Self-regulating characteristic
   (*e*) Minimum inductive effect on welding current by variation in throat area and by presence of magnetic work and fixture materials
   (*f*) Polarity effect of welding current
   (*g*) Ease of measurement of welding current

The advantages of dry-disk rectifier or d.-c. welders, as judged by characteristics in (1) and (2), predominate over the advantages of low-frequency welders.

Bibliography

1. Smith, C. E., "Resistance Welding Machines and Power Supply," A.I.E.E. Tech. Paper No. 48-180, April 1948.
2. Stadum, C. B., "The Nature of Resistance Welding Loads," A.I.E.E. Conference on Electric Welding, Detroit, Mich., December 1948.
3. Blair, R. H., and Smith, C. E., "The Resistance Welding Characteristics of the Dry-Disk Rectifier Welder," The Welding Journal, **27** (9), 679-686 (1948).
4. Deffenbaugh, J. F., Kuzmack, J. A., and Trinkall, F. A., "Laboratory Experience with the Frequency-Converter Resistance Welding Machine," A.I.E.E. Conference on Electric Welding, Detroit, Mich., December 1948.
5. Smith, C. E., "Application of Tri-Phase Metallic Rectifier Machines to Resistance Welding," A.I.E.E. Conference on Electric Welding, Detroit, Mich., December 1948.
6. Brandt, F. L., Wilkins, L. S., Vredenburgh, R. T., Jr., "Some Practical Spot Welding Comparisons of Single Phase vs. Three Phase Converter Welders," A.I.E.E. Conference on Electric Welding, Detroit, Mich., December 1948.
7. Dietz, T. W., "D.-C. Seam Welding," *The Iron Age*, October 1942.
8. Solomon, J. L., "Three-Phase Balanced Load Resistance Welding Machines," The Welding Journal, **26** (5), 426-431 (1947).

Oxyacetylene Flame Shape Cutting in Railroad Shops

Shape-cutting machines serve the railroad shop both in production and in maintenance. Enormous savings are possible through the efficient use of this process

by F. B. Rykoskey

THE fact that oxyacetylene flame cutting in general, and shape cutting in particular is a process of considerable value in railroad shops is not news. But the extent to which they can be used and the savings which they can provide are not so well understood. Their use is particularly timely today because of the intensified need for efficiency in this, as in all other ways.

We are working our way through a period of economic difficulties which have peculiar effects on such public service businesses as the railroads. Costs of man power and equipment have risen steadily and rapidly while railroad income, in proportion, rises very slowly, if at all, in spite of rate increases. In many ways we cannot do much about these basic economic problems since they are out of our control. This makes it all the more important to look for every possible opportunity of reducing costs and thus increasing net revenues through the means we can control and manage.

Of these, the most outstanding is maintenance and repair work. By well-managed maintenance, we can save appreciably in money and time, prolong the life of expensive rolling stock, improve and make more efficient the service of the railroad and contribute effectively to the solution of our over-all economic problems.

For this purpose, a maintenance tool must measure up to two standards—one, of quality, the other of efficiency. The first can never be sacrificed to the second at the cost of safety, durability and operability. The second, however, should not be sacrificed to obtain a higher quality result than is justified by the requirements of the job, although quality must always come first.

Considered on this basis, oxyacetylene shape cutting is an outstandingly valuable means of economizing and expediting the work of railroad shops. It measures up to the requirements, and is in itself a simple and efficient operation without comparison with alternative methods. On a comparative basis, the efficiency of flame shape cutting shows up even better, and often indicates remarkable possibilities.

F. B. Rykoskey is Superintendent of Shops, Baltimore & Ohio Railroad, Baltimore, Md.

This paper was presented before the Annual Meeting of the International Acetylene Association, Pittsburgh, Pa., April 25–26, 1949.

Fig. 1 This locomotive eccentric crank arm, about 4 in. thick, represents plain contour shape cutting of "blanks" ready for finish machining

Shape-cutting machines serve the railroad shop both in production and in maintenance of equipment, although at times there is little real difference. What difference there is usually consists of operating details. Largely, the essential method and its basic values are the same whether a single, once-in-a-blue-moon part or a run of duplicate parts is required. In fact, there are times on the one-shot jobs where shape cutting, by producing an otherwise unavailable part or rough shape at a crucial period, leads to savings of time and money which may be incalculable. Such instances, however, are fortunately none too common, and most of the shop work of the cutting machines (Figs. 1–4) will be done on either sizable batches of duplicate parts or parts which are frequently called for in smaller numbers.

It is in the duplication of parts in quantity that the modern shape-cutting machines reach the peak of efficiency and productivity. The most versatile ma-

Fig. 2 An 8-in. thick blank for a locomotive main side rod is flame cut before forging to eliminate much of the latter operation. The bulging central mass of steel will be forged down to form the long relatively thin rod section

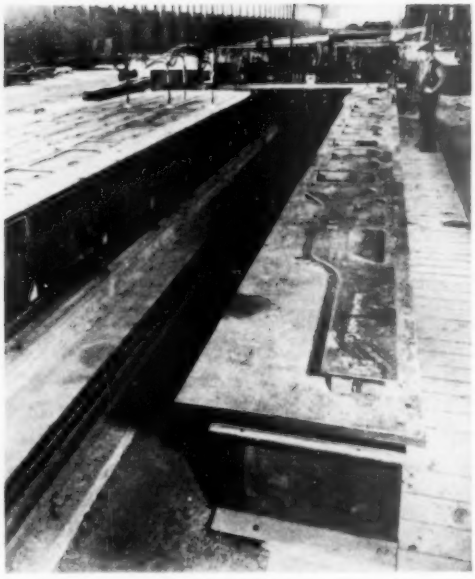
Fig. 3 This locomotive equalizer shape represents the first step in a multiple stage contour-cutting job, 4½ in. thick

Fig. 4 Four in. thick, a locomotive link entails cutting of both the outer contour and the inner slot to close dimensions

chine, with highest cutting area capacity, is a shape-cutting machine of the pantograph type, mounted on a traveling powered carriage (Fig. 5). With such a machine in multiple-torch operation, three complete locomotive side frames have been cut at one time (Fig. 6), and by combining multiple torch and stack-cutting techniques (Fig. 7), smaller parts can be simultaneously produced by the dozens.

Naturally, the type of part has much to do with the useability of these multiple techniques, and while there are numerous locomotive and car parts which can be mass produced, there are also many on which flame cutting is limited to one at a time operations, and others where only a few at a time can be handled. In these latter jobs, it is usually the function of the cutting torch to provide savings over forging and casting, while with mass-produced parts the saving is by flame cutting in quantity rather than employing machine or shear work on individual units.

Flame-cutting of parts which otherwise would require forgings is often a healthy money saver (Figs. 8–11). The torch not only eliminates the forging operation itself—setting up, heating and reheating, handling and other steps—but results in a rough part very near to

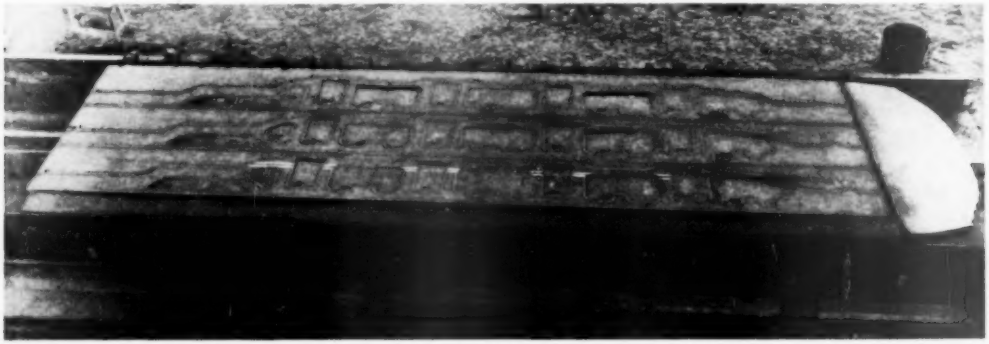


Photo, Courtesy Air Reduction Co., Inc.

Fig. 5 With the entire pantograph assembly carried on a rail-mounted carriage, the shape-cutting travograph provides maximum cutting area and versatility in a standard shape-cutting machine. Here, with special templates, three locomotive side frames are cut from one slab

finished dimension, so that a minimum machining or grinding is required. By so reducing the finishing operations, both the actual cost of the part and the hidden cost which is represented by total time-in-work of a part, are reduced.

In replacing forging operations, the full versatility of the torch is often required. Parts which are forged to rough shape, for instance, are often those which are shaped in more than one plane. Such parts can be obtained either by cutting a flat blank and simply bending



Photo, Courtesy Air Reduction Co., Inc.

Fig. 6 Careful planning of cutting sequence, restraint-free work supports, and elaborate template produced precision results. Frames are 32½ ft. long, 5 in. thick and were not only one of the largest, but one of the most accurate cutting jobs on record

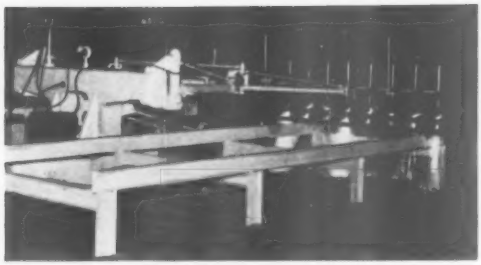


Fig. 7 Here a shape-cutting machine of the pantograph type mounting eight torches cuts eight groups of duplicate parts from a tightly clamped stack of sheet material

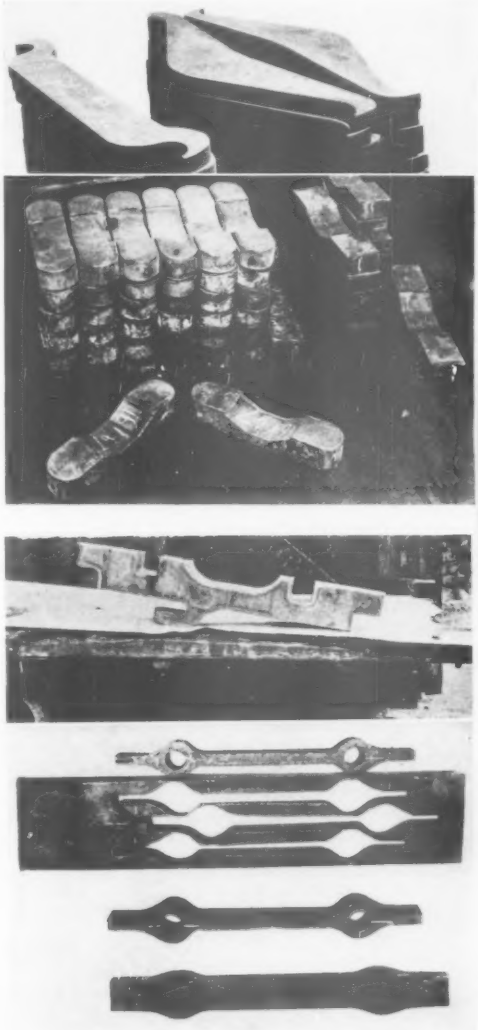
in the second contour plane (Fig. 12), or by flame-cutting to contour in both planes (Fig. 13). The former method is generally used on parts shaped from plate stock; the latter on parts cut from bar, slab and billet stock. Cutting in a third or fourth contour plane is readily done, with the help of various methods of supporting the already shaped sides. One of these is the retention of the scrap pieces to provide a jig for the work to rest upon; another is provision of a suitable special rack or cutting table for quantity work.

In replacing castings, many jobs can be handled in the same way that forging is replaced—multiplane cutting, cutting and bending, etc. In this field, however, it is more often true that shape cutting teams up with arc welding to provide a cheaper, and usually much better part than a complicated casting. Such parts (Fig. 14) for railroad use may range from simple flame-cut sections to weldments involving hundreds of parts in almost as many shapes, yet still less costly and time consuming in production than the castings they replace.

This should not be interpreted as a blanket recommendation for replacing forgings and castings with flame cutting and welding. There are many parts so peculiarly suited to these production methods that no substitute appears logical for them. There are, however, many parts which have been made on the basis of tradition alone by forging and casting for which these methods are wastefully inefficient and costly in comparison to the speed and economy of flame shaping them. The opportunities for genuine savings in such cases are well worth investigating.

One important procedural problem in successful shape cutting of large and heavy parts, such as many of those used in locomotives, is that of accuracy. Its importance lies largely in its effect on possible savings—the closer we can cut to the finish line, the less machining or other finishing will be needed. To obtain the best accuracy, careful analysis of the whole operation has indicated that certain relatively simple measures are helpful.

Templates should be prepared with precision, and handled and stored with care. Setting up and laying out of the work must be planned and executed carefully. Cutting-machine operators, carefully chosen, trained and supervised, play a considerable part. On complicated work, the sequence of cutting, skip cutting, etc., are useful allies. In cutting sizable areas, a non-restraining supporting surface helps to reduce the effects of snaking and other plate movement caused by heat, and so permits cutting closer to the final line. Careful selection of tip styles and sizes, cutting speeds, gas pressures, routine careful mantenance of the machine and equipment—all these are obviously important. Attention to such measures can greatly increase the precision of the cutting and the quality of the results, and produce greater economy.



Photos, Courtesy Air Reduction Co., Inc.

Figs. 8–11 Forgings of varying degrees of complexity and size are replaced by such flame-cut shapes as these

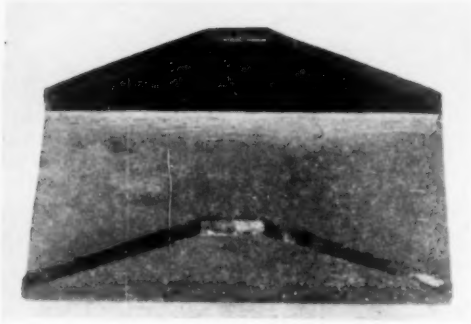
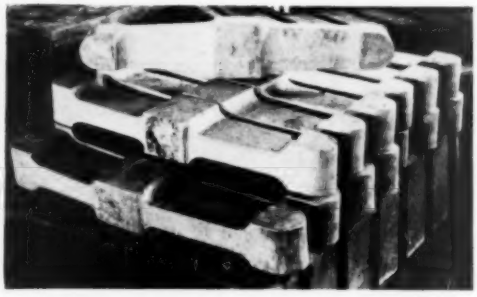
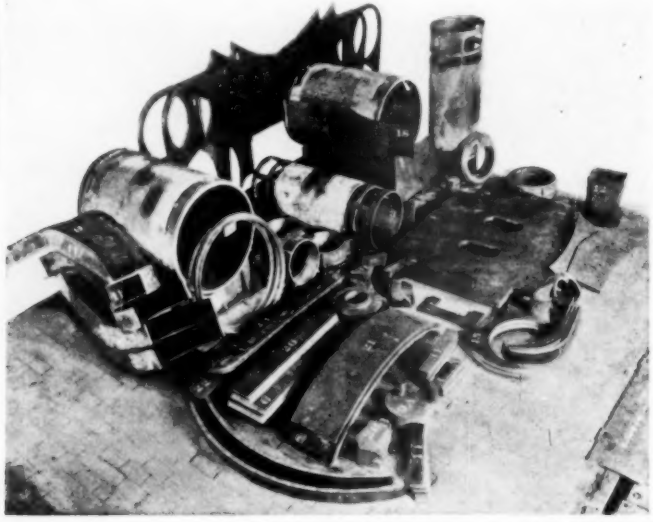


Fig. 12 Many parts, such as this coupler shim, are best produced by flame cutting a flat shape and bending to contour in a second plane



Photo, Courtesy Air Reduction Co., Inc.

Fig. 13 Parts are readily flame cut to contour in more than one plane, replacing or reducing forging or casting work



Photo, Courtesy Air Reduction Co., Inc.

Fig. 14 Replacing an elaborate and complex casting, this collection of over 150 flame-cut shapes, after welding, provides a simpler, stronger locomotive cylinder assembly

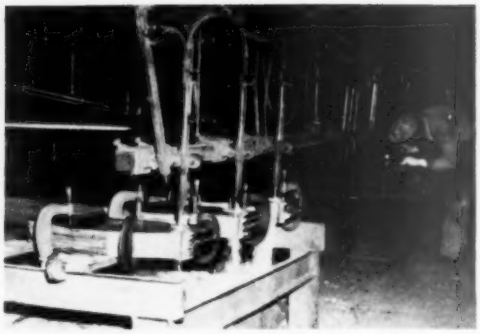


Fig. 15 Stack cutting, with multiple torches, makes the flame a true mass-production tool. Note the heavy clamping required here to hold the sheets in intimate contact, and compare with Figs. 19 and following

Naturally, such attention to the accuracy of the job also tends to reduce the risk of spoiled or poor work. This is an important consideration, particularly in using multiple-torch or stack-cutting techniques, where one error can ruin numbers of parts and sizable amounts of material.

This problem has been, in the past, rather more of a threat with stack-cutting operations than in cutting single thicknesses with multiple torches. The whole theory of stack cutting, since its inception, has been to obtain such intimate contact in a pile of sheets or plates that the steel layers, to all practical purposes, act as one solid thickness of metal. This has been found necessary to prevent loss of the cut, which usually meant scrapping the stack and has required exhaustive clamping measures (Fig. 15) to eliminate air gaps and bring the plates into intimate contact. In spite of the cost and time involved in such set-up work, there are, and continue to be, many applications of the stack-cutting method which are economical and efficient. This is particularly true where highly irregular contours, curves, etc., defy the capacity of shears and other mechanical means. When the difficulty of mechanical shaping of such parts has proved too great or too costly, stack cutting has been applied efficiently despite its elaborate set-up requirements.

There is available today, however, a means of stack cutting which puts the torch in direct competition with shearing, even on straight-line contours, and shows substantial savings in many cases. This is stack cutting by the flux-injection method (Fig. 16), a process developed for flame cutting stainless steels, and recently adapted for cutting mild steel in stacks with little or no clamping

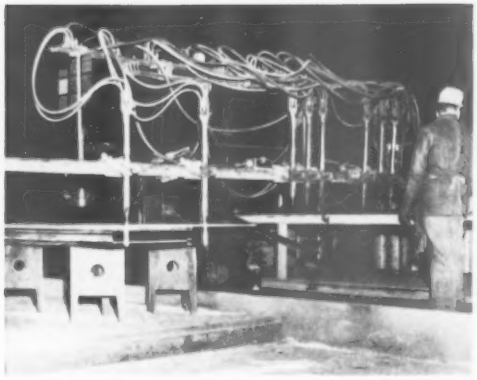
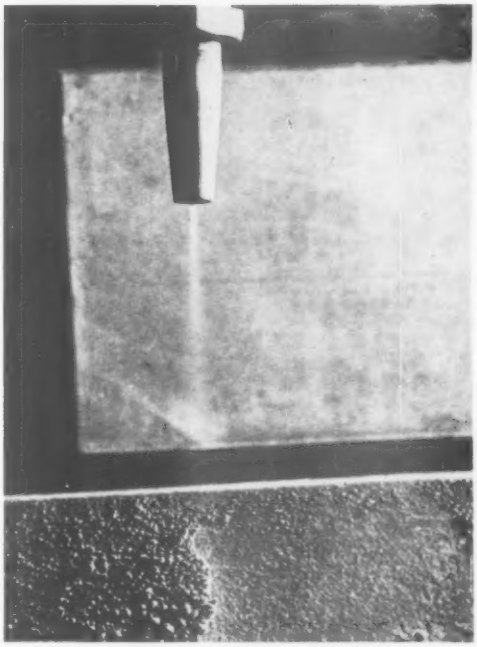


Fig. 16 Stack cutting with flux-injection method and two torches mounted on the shape-cutting machine. Note the complete absence of clamping of the material, 12 plates high

of the plates. The material is simply laid up in a neat pile, clamped, if at all, only enough to prevent shifting and cut. The air gaps, which would stop the cut in conventional operation, appear to have no effect and cutting proceeds rapidly and successfully, yielding a good-quality result.

The flux-injection method uses standard equipment including a three hose-machine cutting torch, plus a special flux feeder unit for each torch (Fig. 17). The secret of its operation is the addition, to the cutting oxygen itself, of a controlled amount of a special finely powdered fluxing agent (Fig. 18). The fluxing medium is carried by the cutting-oxygen stream itself. The flux-feeder unit, coupled into the cutting-oxygen line, dispenses the nonmetallic powder from a vibratory hopper, and it emerges right with the cutting oxygen through the orifice of the tip to reach the exact point of cutting. In the cut the flux acts to increase the fluidity of the slag, clearing the kerf, and aids the oxygen stream in "jumping" whatever gaps may exist between layers. With the flux-injection method, gaps as great as $^1/_4$-in.



Photo, Courtesy Air Reduction Co., Inc.

Fig. 18 The flux emerges from the cutting-oxygen orifice as a part of the oxygen stream to increase fluidity of the slag and help keep the kerf clear for further oxidation

have been so "jumped" without loss of quality or cutting effectiveness. It has also been found possible to stack-cut plates $^1/_4$-in. or so thick without any clamping, straightening or other measures—just as they come to the shop, without particular special handling to preserve or correct their flatness (Fig. 19).

The flux-injection method of stack cutting has been further increased in effectiveness by making it a multiple torch operation. Two torches are in regular use on the shape-cutting machine, each provided with its flux-feeder unit for simultaneous cutting of two batches of duplicate parts. The operation provides even fur-

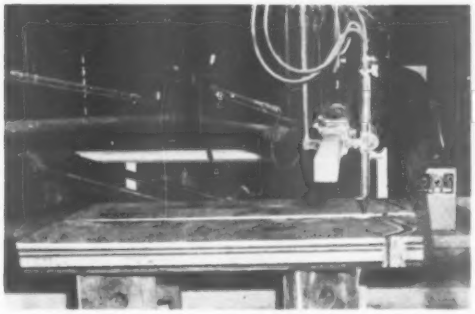


Fig. 17 Except for the flux-feeder units (right), flux-injection equipment is standard. Three hose torches have separate cutting-oxygen supply connected to the feeder units which add the pulverized flux to the oxygen stream

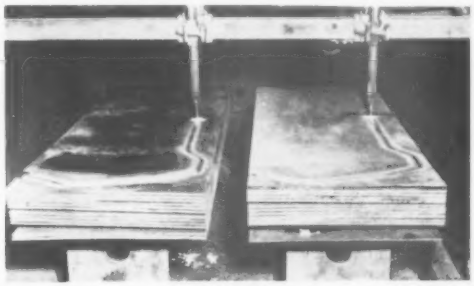


Fig. 19 As flux-injection stack-cutting proceeds, lack of clamping permits further separation of the plates, but the cut is not lost as it would be in conventional stack cutting under such circumstances

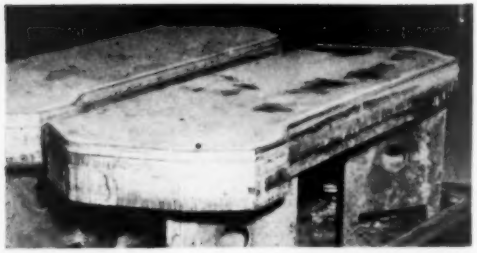


Fig. 20 Clean, flat face of the stack, after flux-injection cutting, is free of gouges, shelfing or other defects which threaten conventional stack cutting without extremely careful clamping. Metal is physically and chemically sound, unchanged by the cutting operation

ther economies in the stack-cutting of miscellaneous small parts from the scrap which results from the main operation.

The parts which are cut by this method are, in the main, sheet and plate shapes used in the fabrication and repair of cars, although any material of suitable thickness can be stack-cut if it is suitable for cutting at all. There is no difference, so far as physical or metallurgical qualities are concerned, in flux-injection cut materials (Fig. 20).

The savings possible with this method have proved highly worth while. Routing production work, week in, week out, has shown an average saving of about 40% as compared with the previous method of shearing and trimming with a hand torch. This is based on the use of a two-torch setup with plates stacked to a height of 4–5 in., with little if any clamping, and on the production of many different sizes and a shapes of parts. The savings on individual shapes run as high as 60%, although most units run closer to the 40% average.

Some of the set-up details (Fig. 21) used for this operation contribute to these savings. To accommodate the variety of contours needed, without the problem of a fixed cutting table, a set of three-legged triangular supports were made up. These supports, arranged as required to hold the work, but leaving a clear area under the actual cutting line, eliminates the problem of cutting into the work support. A more stable, flexible and longer-lived cutting table is possible in this way and the difficulties in cutting which might arise from table irregularities are eliminated.

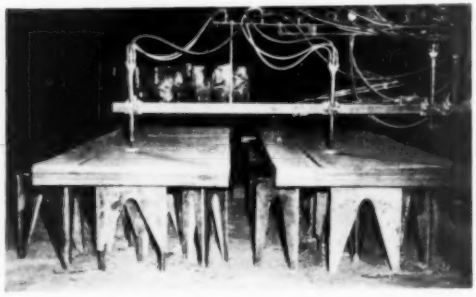


Fig. 21 The three-legged, moveable work supports shown here provide valuable help in speeding and simplifying the stack-cutting job. They can readily be positioned away from the line of cut, and the support area can be arranged to suit the size of the work

Good housekeeping is also important (Fig. 22). It is obvious that a movable cutting support requires a clean, clear floor area, for one thing. It is also helpful to keep the entire operating area neat and clean, and the equipment in top-notch condition. General efficiency is improved by this practice and many little potential hazards to both operating effectiveness and safety are removed. Operators, knowing they can work around the machine with safe footing, confidence, adequate ventilation and eye and respiratory protection, do a better job.

These provisions are, however, basic factors in the shape-cutting operations, whether flux-injection stack cutting, multiple torch cutting on single thicknesses or single-torch work on one heavy slab. The shape-cutting machine of the pantograph type in giving the full value of which it is capable, must be considered much like a precision-machine tool, and operated with all the care and attention possible.

Fig. 22 This over-all view of a shape-cutting machine set-up illustrates the kind of shop housekeeping which leads to better and more efficient work. Frequent cleanups, constant neatness and good machine maintenance cannot be overstressed

While our operations center largely around the shape-cutting machine previously described, it is not the only shape-cutting machine of value in the railroad shop. Many of the same jobs, for instance, can be done with a shape-cutting machine which covers a smaller cutting area, particularly in longitudinal direction, but otherwise is quite similar.

The portable-type cutting machines, while not usually considered as shape-cutting equipment, can and do play a useful part in such operations. Where long arcs or straight lines are required, they can help absorb some of the shape-cutting load, and particularly in trimming plates for fitup, as in welding, they provide a valuable measure of flexibility. Their use cuts down handling operations, and covers many on-the-spot cutting requirements. Finally, in the work of plate-edge preparation for welding, in beveling or grooving, they are indispensable. Fast, flexible and ideally suited to the work,

the portable-type cutting machine also provides the lowest cost means of plate-edge preparation.

Generally, the use of oxyacetylene shape cutting in jobs for which it is suited, is a thoroughly economical operating method. It is very likely that it is not yet fully exploited, even by those of us who have applied it widely in our shops. The jobs for which it has been used successfully, however, point the way to wider use and greater savings with intelligent extension of the process to new fields. No basic industrial process really works miracles—but flame shape cutting seems, at times, to come as close as any process can.

Should the Guided-Bend Test Be Modified?

by L. K. Stringham

INTRODUCTION

Mr. W. Spraragen, Editor
The Welding Journal
33 West 39th Street
New York 18, New York

Dear Sir:

Enclosed is copy of the paper given by our Mr. Stringham at the Tenth Annual Ohio Welding Conference, The Ohio State University, Columbus, Ohio. I was present at this Conference and a number of people, including Professor Green, expressed the desire to have the paper published, and I am submitting it for publication in THE WELDING JOURNAL.

Very truly yours,

THE LINCOLN ELECTRIC COMPANY

A. F. DAVIS
Vice-President

Herewith follows content of a paper entitled "The Misuse of the Guided-Bend Test and Its Affect on Codes," given by L. K. Stringham at the Tenth Annual Ohio Welding Conference, The Ohio State University, Columbus, Ohio, April 7–8, 1949.

IT IS reasonable to assume that each one of you here is interested in welding. It makes no difference whether you are a consumer of welded products, a welding fabricator, insurer of welded structures, member of a code commission, teacher or student of welding, welding operator or manufacturer of welding products.

The consumer is interested because advancement of welding improves products and lowers prices. The fabricator is interested because advancement of welding improves his product and decreases his manufacturing cost. The insurance companies are interested because advancement in welding increases welding construction and increases the insurance business. Industrial commissions are interested in the advancement of welding because an increase in welding results in industrial growth. Teachers and students are interested because it broadens the field of welding. Manufacturers of welding equipment are also interested in the advancement of welding—need I say, "Why?"

One fortunate thing about it is that we are all on the same side of the conference table—just like labor and management. The only trouble is that labor and management frequently do not act as if they are on the same side of the table. I hope we all have sense enough to realize that what is best for one of us is best for all of us. Therefore, our incentive is to work together for a common end, that end being the advancement of welding.

Fastest advancement of welding will result from a combined effort striving to obtain the highest quality welds.

Since the fundamental basis on which industry is founded is to make money, the highest quality weld is the cheapest weld which will meet the service requirements for which the weld is intended.

Since the service requirements of welded joints vary, so will the specifications for the highest quality weld. This can easily be illustrated by citing a few typical applications.

Welds on liquid food containers must not leak; the surface must be smooth, free of undercut and holes in order to promote easy cleaning and prevent spots for food to lodge and decay. Normally, the strength of the weld is no item as it is impossible to meet the other requirements without obtaining the necessary strength.

Welds on pressure vessels must not leak and they must have proper physical requirements.

Welds subject to severe corrosion should have the proper chemical analysis to resist corrosion and should be free of undercut and surface porosity.

Exposed welds on household equipment should be smooth and uniform as appearance is of utmost importance. Unexposed welds on the same equipment; for instance, those to weld in the shelves, only require a minimum of strength.

Therefore, before determining the weld specifications or code requirements, the application must first be analyzed. And here is where I start giving all of you who have anything to do with writing of codes, including myself, the needle.

Many codes have not been set up on the basis of service requirements, or in other words, on an engineering basis. They have been arm-chair engineered. They have been set up on the basis of what can be done and not on what is required. Many codes are obsolete and are impeding the rightful and safe advancement of welding.

It is up to everyone of us to do everything possible to obtain the necessary code revisions to decrease the cost of welding and thus increase its usefulness to ourselves. At the same time we must protect the consumer who is also ourselves.

Since the analyzing of codes in general would be an impossible task for a few minutes talk, I will use the Standard Qualification Procedure of The AMERICAN WELDING SOCIETY, Specification No. B3.0-41T as an example.

Section 102 of this specification is written as follows:

"102. Types of Tests and Purposes

"The types of tests outlined below are to determine the tensile strength, ductility and degree of soundness of welded joints made under a given Procedure Specification. The tests used are as follows:

(*a*) *For Groove Welds*

(1) Reduced-Section Tension Test (for Tensile Strength)
(2) Free-Bend Test (for Ductility)
(3) Root-Bend Test (for Soundness)
(4) Face-Bend Test (for Soundness)
(5) Side-Bend Test (for Soundness)"

Please note that the root-, face- and side-bend tests are specifically designated as soundness tests.

Section 202 of this specification pertains to Operator's Qualification and is written as follows:

L. K. Stringham is Director of Welding Development, The Lincoln Electric Co., Cleveland 1, Ohio

"202. Types of Tests Required

"The qualification tests described herein are specially devised tests to determine the operator's ability to produce sound welds, and may or may not conform in every detail to the requirements of the Procedure Specification. It is not intended that the practices required in the qualification tests shall be used as a guide for welding during actual construction. The latter shall be performed in accordance with the requirements of the Procedure Specification.

"The tests used for operator qualification are as follows:

(*a*) *For Groove Welds*
- (1) Root-Bend Test
- (2) Face-Bend Test
- (3) Side-Bend Test"

Please note that the operator's qualification test is to determine the operator's ability to produce sound welds.

The test results for either of the above tests are given in Section 209 which is written as follows:

"209. Test Results Required

"(*a*) *Root-, Face-, Side-Bend and Fillet-Weld-Soundness Tests*

"The convex surface of the specimen shall be examined for the appearance of cracks or other open defects. Any specimen in which a crack or other open defect is present after the bending, exceeding 1/8 in. measured in any direction, shall be considered as having failed. Cracks occurring on the corners of the specimen during testing shall not be considered. (See Notes I and II.)"

The test requirements and the test results combined are just so much double talk. In fact, today the effect of this combination is just as vicious as being friendly to one with whom you are talking and then stabbing him as soon as he turns his back. It is a stab in the back, particularly to the welding operators and to the inspectors on the job. It is retarding advancement of welding, increasing the cost to the consumer or preventing the contractor from making a reasonable profit, making life miserable for inspectors and fabricators and preventing first-class welding operators from getting a job.

To defend these brash statements, let's examine the guided-bend test (root-, face-, and side-bend) from an engineering standpoint.

The guided-bend test consists of bending the joint 180° around a pin which is 1 1/2 in. in diameter. Figure 1 is the photograph of a simple guided-bend fixture. The test specimen is 3/8 in. thick by 1 1/2 in. wide (the length is not important but is normally between 4 and 8 in.), and is being bent in such a direction that the weld tends to pull away from the two edges of the joint. This bending operating puts the outside surface in tension and the inside surface in compression with the resulting lengthening or elongation of the outside surface and

Fig. 1 Guided-bend fixture

shortening of the inside surface. Figure 2 is the photograph of a specimen which successfully passed the guided-bend test. If a piece of steel 3/8 in. thick is bent in the guided-bend fixture and if the assumption is made that the inside surface compresses by the same amount that the outside surface lengthens, and that the piece does not get thinner, and that there is no stretching of the piece other than around the bend, the outside surface must elongate 20% in

Fig. 2 Guided-bend specimen which met test requirements

order to have the piece of steel bend 180° without failure.

In calculating this, it is assumed that the piece of steel has a uniform tensile strength throughout its length.

By actual test, it has been found that a piece of uniform tensile strength steel elongates 20% in bending the 180° in the guided-bend fixture. This figure of 20% is obtained regardless of the tensile strength of the plate. It is obtained with a 60,000-psi. tensile-strength plate or a 100,000-psi. tensile-strength plate provided the plate bends without failure.

In making a guided-bend test of a welded joint, the tensile strength of the piece however, being bent is *not* normally uniform throughout its length. This would be true only when the tensile strength and yield strength of the weld metal were exactly equal to the tensile and yield strength of the plate, and this seldom happens.

If the plate has a lower tensile strength than the weld, the weld will elongate less than 20% in order for the test specimen to bend 180°. If the plate has a higher tensile strength than the weld, the weld will

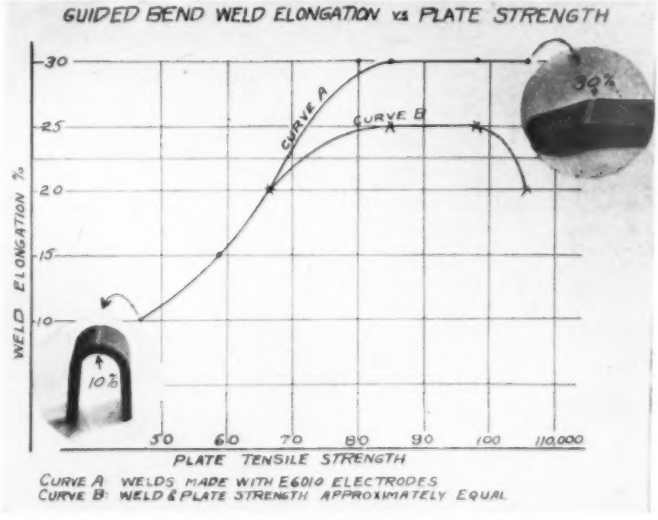


Fig. 3 Curve showing that weld-metal elongation in guided-bend test must increase as the plate tensile strength increases if specimen is to pass the guided-bend test

Photo at lower left of curve shows specimen which bent 180° with only 10% weld-metal elongation. Photo at upper right of curve shows specimen which bent only a few degrees and the weld elongated 30%

elongate more than 20% in order for the test specimen to bend 180°. In other words, the section having the lower tensile strength, whether it is the plate or the weld, will have the greater elongation.

In order to determine exactly how much the elongation of the weld would be affected by varying the tensile strength of the plate, a series of tests were made. A 60,000-lb. tensile-strength (E6010) electrode of $^5/_{32}$-in. size was used to weld $^3/_4$-in. thick plates having the following tensile strengths: 47,000-, 59,000-, 67,000-, 80,000-, 85,000-, 98,000- and 106,000-psi. tensile strength. Root-bend, guided-bend specimens were machined from these plates. Curve *A* of Fig. 3 is a plot of the test results.

As can be seen from the curve, the amount of weld-metal elongation required for the specimen to bend 180° increased as the plate tensile strength increased.

When testing the specimens made from the 80,000- and 85,000-psi. tensile-strength steel, some of the specimen bent 180° and some of them failed. However, the welds all elongated 30%. All specimens made on plates having a tensile strength higher than 85,000 psi. failed at 30% elongation. All failures started at the fusion zone and tore into the weld metal if testing was continued until the specimen broke into two pieces.

A series of tests were then run using the 67-, 80-, 85-, 98- and 106,000-psi. tensile-strength plates, but an attempt was made to pick an electrode which had approximately the same tensile strength as the plate. The lower tensile-strength plates were not used because it was impractical to make a sound weld which had less than 65,000-psi. tensile strength in the as-welded condition.

If the tensile strength of the weld metal had exactly matched the tensile strength of the plate, all of the specimens should have elongated 20% in bending 180°. Actually, the elongation of all specimens bending 180° varied from 20 to 25% as is shown by Curve *B* of Fig. 3.

All welds tested were sound welds. Figure 4 (*b*) is a representative sample.

Fig. 4 (a) Guided-bend specimen of plate having 59,000 psi. (no weld). which was bent without failure with a notch in the surface

Fig. 4 (b) Broken cross section of guided-bend specimen. Cross section showed no porosity, cracks, lack of fusion or other defects

The welds were free of cracks, porosity, undercut and spots of lack of fusion, and yet many failed. Not because of the operator, electrode or steel being used, but it failed because the guided-bend test as it is now used is an impractical soundness test when welding on plates having a tensile strength greater than 70,000 psi. In fact, it is an impractical soundness test.

Test specimens were carefully prepared on the 59,000-psi. plate so that there was a continuous void, approximately $^1/_{16}$ in. in diameter, and which was located in the center of the weld and ran the entire length of the weld. This specimen bent 180° without failure. This specimen, although far from sound, did not fail because there is no stress on the metal at the center of the weld during the bend test.

Some of the higher-strength plates which were welded with electrodes of approximately the same tensile strength failed at as low as 10% elongation even though there were no flaws. This is not surprising since there is an abrupt change in tensile strength at the fusion zone if the plate and weld tensile strength are different. This produces the same effect on a bend specimen as a notch.

To determine the effect of a notch on the steels being used, a guided-bend specimen was made from the unwelded plate material. In each case a notch $^1/_{64}$ in. deep having a 60° included angle was machined into the flat plate. The plates were then bent such that the notch was in the center of the bend.

Figure 4 represents the type of specimen made from plates having 49-, 59- and 67,000-psi. tensile strength. These all bent 180° without failure with the notch in the surface. These steels were not particularly notch sensitive and the notch did not produce failure. An example of a welded specimen tested for notch effect is shown in Fig. 5. Fusion to the root of the weld was not complete and yet the specimen bent 180° without failure.

Figure 6 represents the type of specimen made from plates having 80-, 85-, 98- and 106,000-psi. tensile strength without welds but with a machined notch. Failure started almost immediately upon the start of the bending. Bending was continued beyond failure to show the type of failure. These steels were sufficiently notch sensitive to have the notch cause failure. A failure such as this in a guided-bend specimen of a test joint cut from a pipe line probably would completely shut down welding on the pipe line.

Figure 7 represents an apparently perfect weld which failed on bending. The tensile strength of the plate was 76,000 psi. The tensile strength of the weld was 65,000 psi. Elongation of the weld at failure was 40%. The weld had no flaws.

Perhaps some of you think that the $^1/_{64}$-in. notch across the specimen is too severe. Therefore, for the benefit of those from Missouri, the sample shown in Fig. 8 was made. A guided-bend specimen was made from the 85,000-psi. plate. Stencil marks were cut into the plate at the point

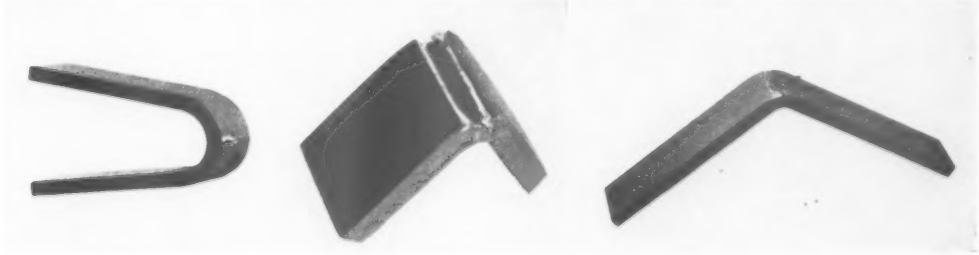


Figure 5 *Figure 6* *Figure 7*

Fig. 5 Guided-bend specimen of weld made in plate having 59,000-psi. tensile strength. Specimen bent without failure even though fusion was incomplete

Fig. 6 Guided-bend specimen of plate having 85,000-psi. tensile strength. Failure started through a surface notch as soon as the plate started to bend

Fig. 7 Guided-bend specimen of apparently perfect weld in 76,000-psi. plate Weld failed at 40% elongation after bending only a few degrees

Fig. 8 Guided-bend specimen made of plate having 85,000-psi. tensile strength
Failure started in stencil marks

to be bent. Failure occurred after bending only slightly.

Anyone who has had any experiences with pipe lines or pressure-vessel construction knows that stencil marks and scars and digs from handling always appear on the surface. If the pipe or pressure-vessel plate material were bend tested at these marks, it would have a good chance of failing. Yet, no one worries about them. Experience has shown that these flaws or marks do not fail in service.

Well, why do we "bust out" an operator just because his sound weld doesn't pass the guided-bend test? Is it because his weld will fail in service? No! He has failed the test because the code erroneously indicates the welder cannot make a sound weld. The inspector has no choice but to "bust out" the operator.

The only right solution is to revise the code. Revise the code so that the operator is tested for the only thing he is responsible for—the job of putting in a sound weld—not for the job of making a weld pass a guided-bend test, which the plate he is using may make it impossible for him to pass.

I personally know of an instance where 33 out of 35 operators failed to pass the guided-bend test. To this day, I don't know how the two welders managed to pass. The pipe they were using for the test was 85,000-psi. pipe. The test pipe was changed to one having 62,000-psi. tensile strength. The other 33 operators then passed the test.

Since the guided-bend test, as now written, does not check a weld for soundness (the only feature it is supposed to check a weld for), I should suggest a good soundness test.

Therefore, I suggest we use the guided-bend test with one slight revision. I believe we should keep the guided-bend test if possible, simply because it is universally used; and most concerns doing code work have a guided-bend test fixture.

The unjustness of the guided-bend test will be removed if Section 209 of A.W.S. Specification B3.0–41T and any similar section in other codes is worded as follows:

> The specimen shall be considered as having passed if (1) there are no cracks after bending, exceeding $^1/_8$ in. measured in any direction. Cracks occurring on the corners of the specimen during bending shall not be considered, or (2) in event the specimen does not bend without cracking $^1/_8$ in., there are no voids, slag inclusions or spots of lack of fusion greater than $^1/_8$ in. when measuring from the top to the bottom of the weld, and the total voids in the broken cross section of the guided bend specimen do not exceed 5% of the total area of cross section of the specimen. With this revision the operator will be tested as intended, i.e., to determine his ability to make a sound weld.

Since it is for the best interest of all of us to have the codes correct, it is the duty of each one of us to do everything possible to rectify errors in codes or change codes which have become obsolete due to the advancement of the welding industry. There are many welding codes which need correcting. I picked the guided-bend test as an example, because I believe it is most seriously affecting the entire welding industry. It unnecessarily adds to the cost of the finished product, continually causes trouble for constructors and inspectors, deprives good welding operators from a job and, lastly, it continually causes the electrode manufacturers trouble.

Let's get the welding codes corrected!

The foregoing is published for the primary purpose of inviting discussion by all interested A.W.S. Technical Committees, Welding Engineers, other regulatory bodies and industry. Please send discussions to: The Editor, The Welding Journal, 33 W. 39th St., New York 18, N. Y.

(Continued from page 727)

Brazing in Salt Bath Furnaces. Iron Age, vol. 163, no. 23 (June 9, 1949), pp. 66–68.

Brazing, Electric. Redesigning Metal Parts for Electric Furnace Brazing, H. M. Webber. Matls. & Methods, vol. 29, no. 4 (Apr. 1949), pp. 58–62.

Brazing. Salt-Bath Brazing. Metallurgia, vol. 39, no. 233 (Mar. 1949), pp. 257–259.

Buildings, Steel, Welding. Light Steel Frame Workshop Building of Unorthodox Design in Total Arc-Welded Construction, A. E. R. Stephenson. Civ. Eng. (Lond.), vol. 44, no. 512 (Feb. 1949), pp. 82–84; no. 513 (Mar.), pp. 150–152.

Buildings, Steel. Welded Steel Framed Buildings, J. T. Phillips and F. J. Daniels. Structural Engr., vol. 27, no. 3 (Mar. 1949), pp. 123–145.

Casting Vs. Welding. Economies of Castings and Weldings, E. C. Moore. Inst. of Welding—Trans., vol. 12, no. 2 (Apr. 1949), pp. 27–29; see also Machy. (Lond.), vol. 74, no. 1904 (Apr. 21, 1949), pp. 517–519.

Cars, Passenger, Great Britain. All-Steel Fabricated Railway Coaches. Engineer, vol. 187, no. 4867 (May 6, 1949), pp. 506–507; see also Engineering, vol. 167, no. 4350 (June 10, 1949), pp. 536–538.

Cutting Tools, Manufacture. Special Electrodes for Depositing Cutting Edges on Cutting Tools, V. V. Danilevsky. Engrs.' Digest, vol. 10, no. 1, (Jan. 1949), p. 26.

Electric Welding. Arc Welding of Aluminum and Its Alloys, A. Schaerer. Light Metals, vol. 11, no. 130 (Nov. 1948), pp. 631–638; no. 131 (Dec.), pp. 664–671; vol. 12, no. 132 (Jan. 1949), pp. 12–19; no. 133 (Feb.), pp. 109–12; (discussion), pp. 112–114.

Electric Welding. Arc Welding Offers Progress in Machinery Manufacture and Structural Building, C. G. Herbruck. Steel Processing, vol. 35, no. 4 (Apr. 1949), pp. 191–195.

Electric Welding, Arc. Inert-Arc Plug Welding of Aluminum, K. N. Smith. Industry & Welding, vol. 22, no. 3 (Mar. 1949), pp. 58–60.

Electric Welding, Arc. Inert-Arc Welding of Less Weldable Metals, M. J. Conway. Machy. (Lond.), vol. 74, no. 1903 (Apr. 14, 1949), pp. 478–486.

Electric Welding, Arc. Quick Welding of Aluminum Products, W. Lukemeier. Welding Engr., vol. 34, no. 4 (Apr. 1949), pp. 36–37, 73.

Electric Welding Electrodes. Tungsten: To Save or Not to Save, R. W. Tuthill. Welding Engr., vol. 34, no. 3 (Mar. 1949), pp. 42–45.

Electric Welding Machines. Analysis of Welding Transformer Characteristics, N. S. Siunov. Engrs.' Digest, vol. 10, no. 3 (Mar. 1949), p. 79.

Electric Welding Machines. Big Welders in Czechoslovakia, B. Fisher. Welding Engr. vol. 34, no. 4 (Apr. 1949), pp. 62, 64.

Electric Welding Machines, Control. Smooth Regulation of Spot Welding Sets by Means of Choke in Their Secondary Circuit, A. Z. Blitstein. Engrs.' Digest, vol. 10, no. 3 (Mar. 1949), pp. 91–92.

Electric Welding Machines. Petrol-Engined Welding Set. Engineering, vol. 167, no. 4340 (Apr. 1, 1949), p. 312.

Electric Welding Machines, Portable. Booster Supplies Hydraulic Pressure, W. Cain. Machine Design, vol. 21, no. 4 (Apr. 1949), pp. 115–116.

Electric Welding, Resistance. Cleaning Aluminum Sheet Prior to Spot Welding, G. H. Boss. Metal Progress, vol. 55, no. 4 (Apr. 1949), pp. 499–503; no. 5 (May), pp. 668–673.

Electric Welding, Resistance. Production Process . . . Their Influence on Design, R. W. Bolz. Machine Design, vol. 21, no. 1 (Jan. 1949), pp. 121–126; no. 2 (Feb. 1949), pp. 103–110.

Electric Welding, Resistance, Quality Control. Resistance-Weld Failures Minimized by Test Method Applied to Diversified

(Continued on page 809)

Rigid-Frame Harbor Shed

World's largest unobstructed single-span harbor shed realizes full advantages of welded rigid-frame construction

by G. L. Revell

A COMBINATION of progressive thinking in design and intelligently planned fabrication and erection techniques marks the completion of the world's largest unobstructed single-span harbor transit shed as an outstanding accomplishment in welded structural steel work. The use of welding on this structure resulted in cost savings, material savings and speed in completion. Most important of all, however, it resulted in the creation of a more useful and more permanent structure. The shed is built to withstand earthquakes and its large unobstructed interior presents the maximum use of space for storage and allows freedom of movement.

The transit shed, in the Harbor of Long Beach, Calif., is 1200 ft. long, 200 ft. wide and 40 ft. high. The structure is composed of 32 welded 200-ft. span rigid frames. Total structural steel in the building is 2625 tons.

The building was designed by R. D. Sandham, assistant engineer under the direction of R. R. Shoemaker, chief engineer, and R. J. Amar, port manager, all with the Long Beach Harbor Commissioners. Steel was fabricated by Pacific Iron and Steel Co., of Los Angeles.

The decision to use a welded rigid-frame type of construction was made on the basis of several considerations. A great many buildings in the Los Angeles-Long Beach area were destroyed by earthquakes in 1933. It was felt that the design of the shed as a welded rigid frame would withstand possible future quakes better than any other type of structure. It was also determined that this type of building would conserve steel and make the best practical use of the steel supply available. The savings in steel realized through the use of welding was approximately 7% over what would have been required for a riveted structure. The total savings in cost for this type of building over other types of structures was estimated to be 20%.

A further consideration influencing the decision was the urgency of accommodating the rapidly expanding trade in the Long Beach Harbor. Because they were welded, the rigid frames could be shipped to the erection site in larger prefabricated sections, quickly assembled and raised into place. The 32-man erection crew was able to raise and connect with I-beams, 8 frames in one 6-hr. shift, a speed next to impossible with conventional erection methods. The total shop time spent in prefabrication was 30 working days and the total erection required 90 days.

The advantages to the users of this building realized through this type of structure are apparent (Fig. 1). The large area under cover completely free of supporting columns permits the maximum amount of this space to be used for storage. Lifting trucks and other conveyors are given more freedom, and hence are more efficient in their operation.

The erection of this building presents an interesting story of the execution of a good welded design through well planned and thoroughly coordinated welding and erection techniques.

G. L. Revell is a Welding Engineer, Lincoln Electric Co. located in Los Angeles, Calif.

Fig. 1 Completed structural frame work for the world's largest unobstructed, single-span transit harbor shed

The 1200-ft. long building is comprised of 32 welded 200-ft. span rigid-frame trusses with office space at either end of the building

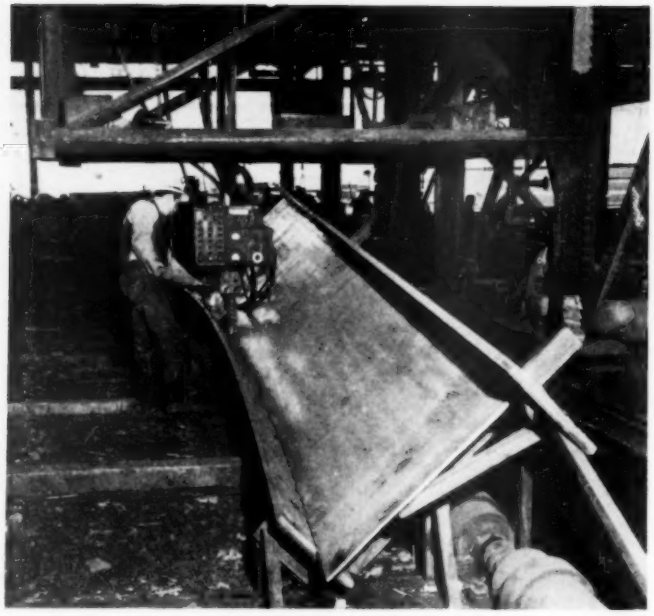


Fig. 2 Controlled welding conditions with automatic submerged arc welding were worked out to close limits to prevent cracking in the 1 1/2-in. thick flange plates during the critical cooling period of the weld

Six hundred amperes were used at a speed of 24 in. per minute. Head is mounted on a hydraulic piston for movement up and down and on a traveling gantry for lateral movement, all controlled electrically from the central push-button station

The thirty-two 200-ft. span rigid frames were made by welding together two end hip joints and seven girder sections. The frames were prefabricated in the shop as completely as was practical. Fairly heavy material was used in their fabrication.

Flange plates were 1 1/2 by 16 in. and web plates were 3/4 by 48 in. Because material with cross sections as thick as these are not always as ductile as smaller plate and do not deform readily, a great deal of strain is put on any weld in them during the cooling period. Automatic submerged arc welding was used, therefore, in welding the web and flange plates together so that controlled welding conditions could be worked out to prevent cracking.

Before tack welding, the web plates were first peened along the edges so that a small protrusion was made on the edge about every foot. This created a 1/32-in. gap between the web and flange when they were tacked which permitted more contraction to take place without placing the strain on the weld during the critical cooling period.

Angle stiffeners were also tacked on one side between flanges to prevent rotation of the flange when fillet welding the opposite side. The assembled section was then placed in a positioning jig which tilted the flange plates at an angle of approximately 30° from the horizontal (Fig. 2).

The welding head for welding the sections is mounted on a traveling gantry whose movement is controlled electrically from a central push button station at the head. The head moves up and down on a hydraulic piston so that it can follow the contour of the weld. It was found to be extremely important in avoiding cracking to maintain the correct relation between current and speed of travel. The welding current used was 600 amp. at 30 v. with a travel speed of 24 in. per minute. Welding was completed in one pass on each side of the joint.

The welding of the web and flange plates of the hip joints was also done with the automatic submerged arc process. A self-propelled tractor mounted head

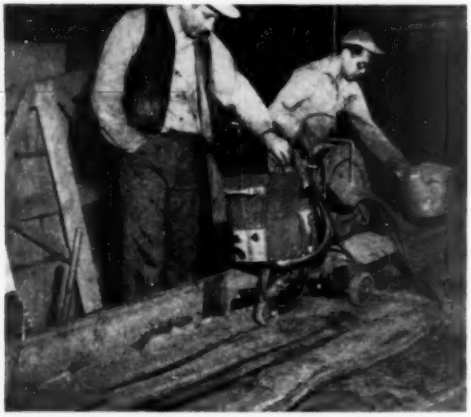


Fig. 3 The curved hip joints were welded automatically with a tractor mounted head

Five hundred amperes at a speed of 20 in. per minute were used

Fig. 4 Hip-joint sections positioned for fillet welding stiffeners to web plate. An E6012 electrode was used

Fig. 5 Hip-joint sections positioned for welding stiffeners to the flange plates

Additional speed possible with down-hand welding justified handling the joints and sections for welding stiffeners

was used to follow the curved contour of the joint. The tractor was guided by hand with the aid of a small wheel (Fig. 3). One pass was made with a travel speed of 20 in. a minute and a welding current of 500 amp. and 30 v. For all automatic welding a $^{5}/_{32}$-in. electrode was used.

After the web and flange plates were welded, girder sections and hip joints were positioned on the floor of the shop for flat fillet welding stiffeners to the web plate. For welding stiffeners to the flange plates the sections were positioned so that all welds were made in a down-hand position. These welding operations are seen in Figs. 4 and 5.

Four shop splices were made joining the girder sections so that each frame could be trucked to the erection site in five separate sections, consisting of two hip joints and three girder sections. The sections as trucked were approximately 40 ft. long and weighed about ten tons. These sections were unloaded at the Harbor pier site and placed on the ground in position for welding and in the correct sequence for erection.

Four field splices, two joining the hip joints and two joining the three girder sections, were made in each frame on the ground before it was erected. The joints were located and aligned using a transit, then jacked up, shimmed with timbers and tack welded. The joints were double beveled with a 60° included angle, leaving a $^{3}/_{16}$-in. land (Fig. 6). The fit-up varied from a good $^{1}/_{8}$ to an excessive $^{5}/_{8}$ in.

The web-plate joints were welded first. A $^{3}/_{16}$-in. E6010 electrode was used for the root pass. The weld was finished with two passes of a $^{1}/_{4}$-in. E6020 electrode (Fig. 7).

Next, the vertical welds were made joining the $1^{1}/_{2}$-in. flange plates. All welding on the flanges, including tack welds, was done with a lime-ferritic type electrode, "Shield-Arc LH-70." This type of electrode was used because it deposits a high-strength ductile weld in steels, such as this $1^{1}/_{2}$-in. plate, that have a

Fig. 6 Lining up field joints with a transit, jack and timbers

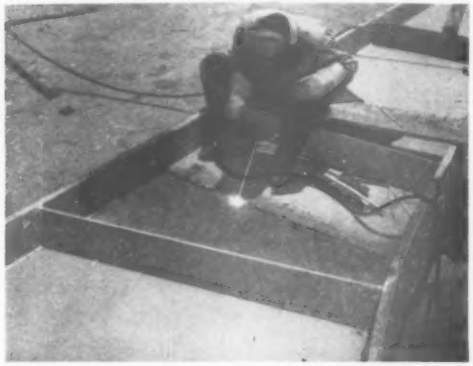


Fig. 7 After joint was lined up and tack welded, the web plates were welded first

The root pass in the double bevel 60° V joint was made with a $^{3}/_{16}$-in. E6010 electrode, followed by two passes with a $^{1}/_{4}$-in. E6020 electrode

tendency to harden and crack. It was also used because of its operating characteristics which permit using higher currents and building up in wide passes. It would have been difficult to use an E6010 electrode on joints where the gap was excessive because of its tendency to dig out, burn through and increase the gap. A $^3/_{16}$-in. electrode was used with 225 amp., completing the joint in a total of four passes, two inside and two outside. In some joints a small steel shelf was made at the bottom of the joint on which to start the weld. It is estimated that this type of electrode cut the welding time for these joints in half and because it was possible to complete the joint in only four passes, dimensions on the frames were held to a tolerance of $^3/_{16}$ in. (Figs. 8 and 9).

After the web and flange plates were welded, splice plates were added to the flange joints. Splice plates were used to provide increased rigidity during erection since only one side of the web plate could be welded on the ground (Figs. 10 and 11). Over 70% of the welding on the rigid frame was completed before they were raised into position.

Three 20-ton cranes were used to pick up the assembled 50-ton rigid frames and raise them into position while connecting I-beams and trusses were attached. Figure 11 is a close-up view of the base plate connection of the hip girders. The pin connection was assembled on the girder and slipped over the four anchor bolts in the base plate. Each rigid frame rests on 5-in. diam-

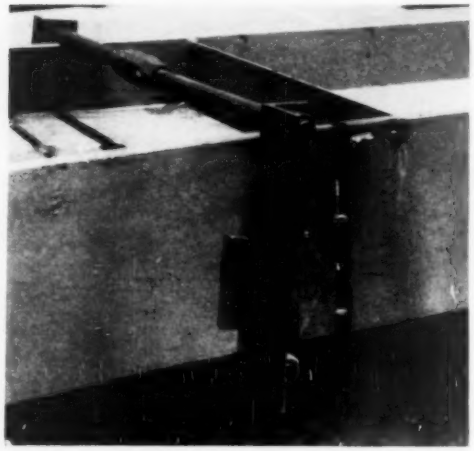


Fig. 8 Joint preparation in $1^1/_2$ in. thick flanges was a double V 60° bevel with a $^3/_{16}$-in. land

Gap varied from $^1/_8$ to $^1/_4$ in. All welding on flanges was done with a lime-ferritic type electrode, "Shield-Arc LH-70." This type electrode minimizes tendency to crack and permits higher currents and wider beads

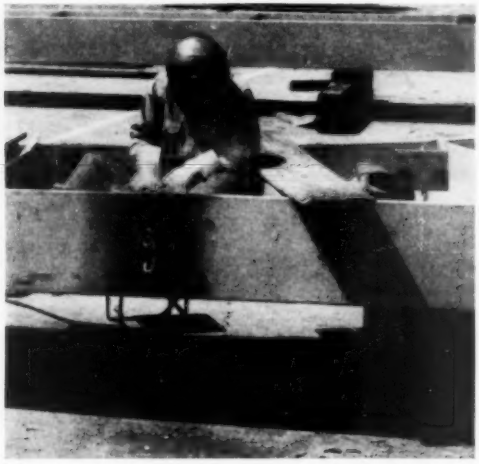


Fig. 9 Welding vertically on the inside of the flange

The vertical joints were completed in a total of four passes, two inside and two outside, using a $^3/_{16}$-in. electrode with 225 amp. Because of the small number of passes, dimensions on assembled frame were held to tolerance of $^3/_{16}$ in.

Fig. 10 Splice plates were added to the splices to give added rigidity to frames for erection. Only one side of the web joint welded on the ground. Frames had four field splices, four shop splices

Fig. 11 Close-up of splice plate after welding

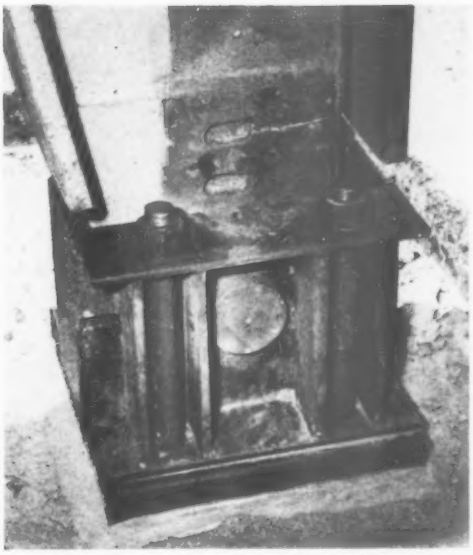


Fig. 12 Detail of hip girder connection to base plate

Pin connection assembled to girder (see Fig. 4) and slipped over four anchor bolts in base plate. Five-inch diameter hardened pin permits movement in case of earthquake and allows for settling in Harbor area

eter hardened pins in the connection assemble so that a slight movement will be permitted in case of future earthquakes. The pin will also allow the building to adjust for any settling that might occur in the Harbor area (Fig. 12).

The final welding on the frame joints was made after the frames were erected and connected. The overhead welds on the flange plates were completed in ten passes while the vertical welds on the web were made in two passes (Fig. 13).

Fig. 13 After girders were raised and I-beams attached the joints were completed by making ten passes in the flange plate and two passes on the web plate. An E6010 electrode was used for these passes

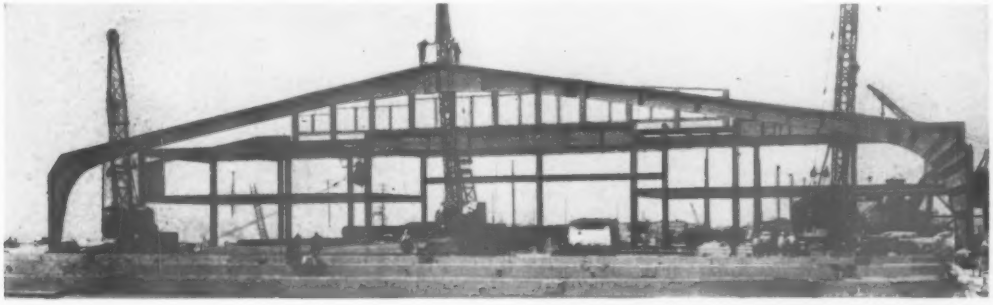
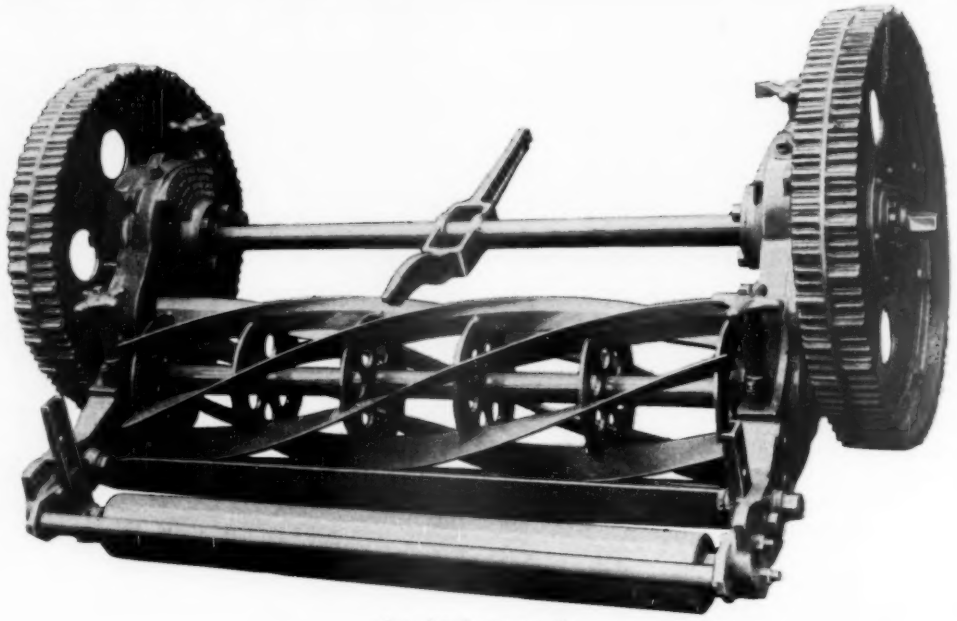


Fig. 14 Showing one of the girders and columns in position

PRACTICAL WELDER AND DESIGNER



Completed mower unit

Arc Welding in the Mower Industry

by John A. Perry and C. A. McClean

THE year was 1830, the place was England and young Edward Budding stood watching a cloth-clipping machine with more than the usual amount of attention. Why, he thought, couldn't this same principle be applied to the cutting of grass? He mulled the idea over awhile and a year later Mr. Budding was granted a patent on the first lawn mower.

It was not until 25 years later that this machine appeared on the American scene. Since then it has been playing an increasingly important part in our day-to-day living. In fact, the lawn mower has become a household word for anyone with a patch of grass.

The general public is less aware that an industry within an industry has arisen in the mower field. These companies are engaged in the manufacture of mowers other than the conventional lawn mowers. The Worthington Mower Co., for example, makes a complete line of mowers for use on airfields, private estates, golf courses, parks and other large expanses of grass and foliage-covered ground.

John A. Perry and C. A. McClean are with the Technical Sales Division, Air Reduction Sales Co., New York 17, N. Y.

Tightening clamps with air wrench. These clamps are used to hold the blades in position during welding

Arc-welding disk to shaft in specially designed jig. This jig permits assembly, welding and removal (floor-to-floor) in about 3 min. A feature of this jig is that it may be easily changed to handle any of the 6 types of rolls manufactured

Before assembly, the end disks are provided with a "grass excluder." This consists of a small steel ring arc welded to the disk

These mowers are available in combinations referred to as "gangs." A number of these gangs, operating in parallel, cut a tremendous amount of grass per hour. The airfield "grass blitzer" with a nine-gang combination cuts 46 acres per hour with a swath 21 ft., 2 in. wide. In comparison, a time-study test showed that a 7-ft. sickel bar attached to a farm-type tractors mows approximately $3^1/_2$ acres per hour

As in so many other industries, welding plays an important part in the Worthington Mower production setup. In fact, this company has been one of the pioneers in the use of welding in the mower industry. They were quick to realize that welding was the answer when the ultimate product had to be rugged and durable to stand up under rough terrain and mow through tough rank growth. And, as welding develops and

The reel is then mounted in brackets which place the shaft directly beneath the ram of a straightening device. By means of a magnifying viewer and a guide line, it is possible to check for the perfect alignment required. The end use of the unit requires that alignment be held 0.001–0.003 in.

Arc welding an assembled reel for a 30-in. mower using Airco No. 394 electrodes. The reel may be rotated within the jig, permitting ease of welding. Using this jig, insertion, welding and removal of reel may be accomplished in $2^1/_2$ min.

progresses, all industry profits. Recently Airco introduced a new low-hydrogen type electrode, especially designed to prevent underbead cracking in weld deposits. It is known as the Airco No. 394.

When this new electrode was brought to the attention of the Worthington engineers they decided to try it out in the welding of high-carbon-steel mower blades to mild steel disks. The Airco No. 394 cut down rejects due to weld cracking by 50 to 60% with an accompanying saving in rewelding time. In addition, a higher rate of welding speed was attained which resulted in a positive increase in mower production.

Diesel Cylinder Head Repair

by J. W. Kenefic and R. E. Barber

A LARGE railroad in the northwest solved the problem of how to reclaim fractured Diesel cast-iron cylinder heads. The answer was provided by gas welding.

The fractures seemed to occur at the turbulence chamber and across the bridge between the valve ports.

Fig. 1 The operator is gas welding a fractured Diesel cast-iron cylinder head.

J. W. Kenefic and R. E. Barber are with the Railroad Dept. of Air Reduction Sales Co., New York, N. Y.

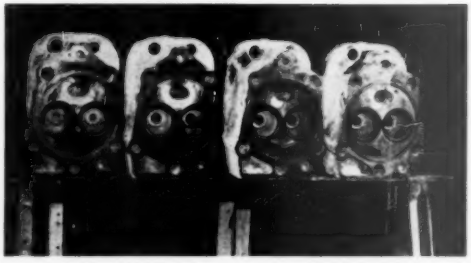


Fig. 2 Diesel cast-iron cylinder head reclaimed by gas welding

In the technique applied by this railroad, the fractures were first cleaned by chipping and grinding. The casting was then placed in a specially built firebrick furnace. The furnace was 36 x 40 which allowed sufficient room between the casting and the furnace walls. This space is then filled with charcoal, covered with sheet asbestos and, after lighting, is allowed to heat for approximately four hours. After this preheat period, the casting is slowly brought up to an even cherry red using two oxyacetylene welding torches. This last operation takes about fifteen minutes.

To obtain the dense, nonporous, machinable deposit required, this railroad uses Airco No. 9 cast-iron welding rod and Atlas flux.

After the welding operation, the head remains in the fire and, following a cooling period, the head is removed and machined.

The operating costs on the job were $30 per cylinder head as compared with $300 for a new cylinder.

How to Weld Pipe

Helpful hints for making good pipe-line welds

by F. C. Geibig

THERE are two important uses for pipe welding. The first, of course, is on welded pipe systems for water and air lines, radiant heating installations and air-conditioning systems. The second is for building useful things from pipe, such as the fences, gates, sheds, shop horses, clothes driers and grape arbors.

On such things as water lines and radiant heating systems for homes, driveways and shops, welded pipe is excellent. You get the leakproof joint you need when you bury pipe underground or when the pipe is in a hard-to-get-at location. Don't forget that if the pipe will be under pressure the welding must come up to codes and standards for pressure systems. The line should always be tested to make certain that it is tight.

Pipe is also ideal for building things like fences and shop equipment. When you close off the ends of the pipe to make it waterproof you have a structure that is easy to paint and will not rust or corrode easily. Pipe is a strong and inexpensive construction material because often you can pick up used pipe from the scrap yard.

F. C. Geibig is Development Engineer with The Linde Air Products Co., Newark, N. J.

GETTING READY TO WELD

The simplest job in pipe welding is joining two small pieces to make a long piece. This is known as a butt weld. If the pipe is $2^1/_2$ in. or less in diameter, and has a wall thickness of about $^3/_{16}$ in.or less, it's easy to get ready to weld. Make sure that the edges of both pieces have been cut square. Then clean the edges with a wire brush to remove rust, grease and slag. If the pipe wall is thicker than $^3/_{16}$ in. you will have to bevel the ends of both pieces. Each end should be beveled to an angle of 30 to 45° so that when you put the two ends together you will have a vee of 60 to 90°. This vee, as shown in Fig. 1, makes it easy to get the weld metal down to the bottom for good penetration.

You can make the bevel by grinding, filing, or with your cutting attachment or blowpipe. It's easier to use

the cutting attachment or blowpipe. Do the cutting just as you would cut a bevel on flat steel. Hold the nozzle at an angle, as shown in Fig. 3. When both edges have been beveled clean them off with a wire brush before you start to weld. Clean the slag from the inside of the pipe, too.

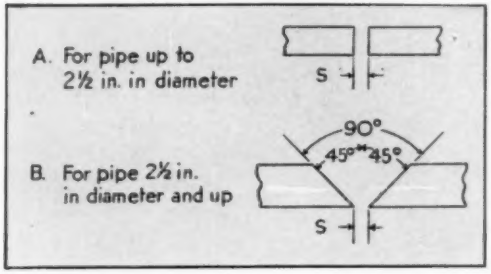


Fig. 1 Prepare the edges of pipe like this. Pipe ¼ in. wall thickness and up must be beveled

Nominal Diameter, in.	Beveled Single Vee, 90-Deg. Incl. Angle, in.	Not Beveled, in.
3/4 to 1 1/4	—	3/32
1 1/2	—	1/8
2 to 2 1/2	3/32	1/8
3 to 8	3/16	—
8 to 12	1/8	—

Fig. 2 Recommended spacing between pipe ends

Fig. 3 Use your cutting blowpipe or attachment for beveling. Hold it at an angle and cut for several inches, then rotate the pipe

MAKING A BUTT WELD

Connect a medium-sized welding head to your blowpipe and adjust the flame to neutral. You will need the 1/8-in. steel welding rod on this job, too.

Now line up the two pieces of pipe in a length of angle iron or a holder so they won't roll off the table. Space the ends about 1/8 in. apart and then make a tack weld at four points around the pipe. The chart in Fig. 2 tells you the proper spaces to leave between pipe of various diameters.

Fig. 4 Make several tack welds and begin the final weld between two of them. Start to weld halfway between the top and side and move to the top

To make a tack weld you heat a small spot on the edge of each pipe. Keep heating until the spots begin to melt. At the same time hold the end of your welding rod in the flame and when the spots on the pipe melt, place the welding rod in the puddle and melt off enough metal to bridge the space between the pipe ends. Make the tack welds carefully so they will not be a weak spot in the final weld. Hold the blowpipe and the rod so that they form an angle of about 90° with each other. This will give you an angle of about 45° between the blowpipe and the pipe, and the rod and the pipe.

After you have made four tack

Fig. 5 Rotate the pipe so the place you stopped is halfway between the top and side. Then continue the weld. Rotate the pipe as often as you need to finish the weld

welds, you are ready to begin the final welding. Turn the pipe so that you will start to weld about halfway between any two tack welds. Heat two spots on the ends of the pipe just as you did when making tack welds. When the metal melts and a puddle forms, place the welding rod in the puddle to add metal and bridge the space between the pipe ends.

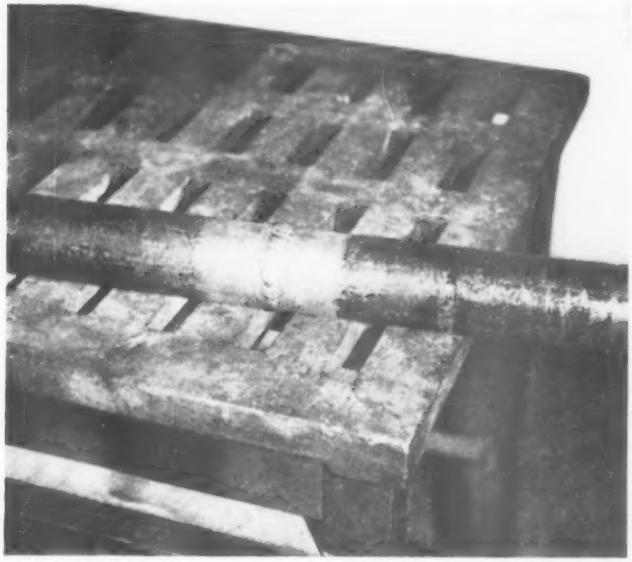


Fig. 6 On the finished weld the weld metal should be about $^1/_{16}$ in. higher than the surface of the pipe

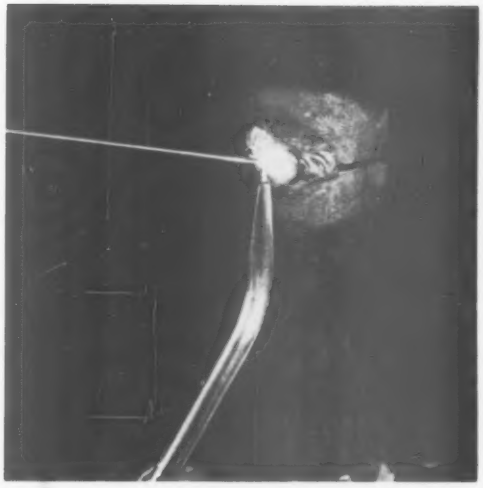


Fig. 7 Hold the rod and blowpipe like this for a horizontal weld. The flame helps keep the puddle in position

Hold the blowpipe so that the flame is pointed slightly upward. Be sure that both edges of the pipe melt all the way to the inside wall. Then start to move the blowpipe, rod and the puddle toward the top of the pipe. When the puddle gets near the top of the pipe stop welding. Roll the pipe so that the weld is now on the side and reheat the metal at the place you stopped welding. When a puddle forms add molten metal from the welding rod and move the weld up the pipe just as you did before. When you reach a tack weld, be sure to remelt the surface as the weld puddle moves along. Otherwise the metal in the shallow tack weld will not be thoroughly fused and you will get a weak spot in the pipe and a possible leak. (Some code work requires that tack welds be completely melted out as the weld is made.)

The weld metal shoud be about $^1/_{16}$ in. higher than the surface of the pipe. If it is not high enough when you finish the weld, start over and deposit another layer of weld metal. But be sure to melt the first layer as you deposit the additional molten welding rod.

If a hole burns through the pipe, it is not serious. Roll the pipe so that the hole is on the side and then fill up the hole. Of course, this kind of a filler should not be made if you are going to use the pipe in a piping system. But if you are making a grape arbor, it will be satisfactory.

Fig. 8 This is how an overhead weld will look from below. The flame should point almost straight up

HORIZONTAL WELDS

When the pipe you want to weld is standing upright weld around the pipe as shown in Fig. 7. Space the pipe and make four tack welds just as you did before. Start the final weld about halfway between two of them. Hold the blowpipe as shown in Fig. 7. Then heat a spot about an inch long. Get the heat in between the edges so that they melt and flow together. When a puddle forms, place the rod in the puddle and add weld metal. The rod also should be horizontal and almost parallel with the line of weld. Here again, the rod and the blowpipe tip should form an angle of about 90°. When you add rod to the puddle, lower the blowpipe so that the flame points slightly upward. The force of the flame will help to keep the molten puddle in place. Be sure that both the rod and the pipe are melted but keep the puddle as small as possible. If it seems that the puddle is about to get out of control and run down the side of the pipe, draw back the flame for a few seconds and the puddle will cool slightly.

OVERHEAD WELDS

When you make an overhead weld, here's how to do it. Space the pipe as you did before and use the same size welding tip and flame adjustment. Make tack welds as you did before. Start to weld at the bottom with the blowpipe flame pointing almost straight up and with the welding rod at a slight angle. This position is shown in Fig. 8. Heat an area about $^3/_4$ to 1 in. long on both ends of the pipe until they start to melt. Then bridge the gap with the molten puddle. Heat, but don't melt the edges very far ahead of the puddle. Keep the end of the welding rod in the puddle. Keep the molten puddle as small as possible but be sure to get complete penetration. If the puddle seems to be getting out of control, flick the flame away for a second. This will let the molten metal harden a little.

Fig. 9 Place the branch on the header and mark the hole with a piece of sharpened soapstone

Fig. 10 Cut the hole in the header then mark and trim the end of the branch

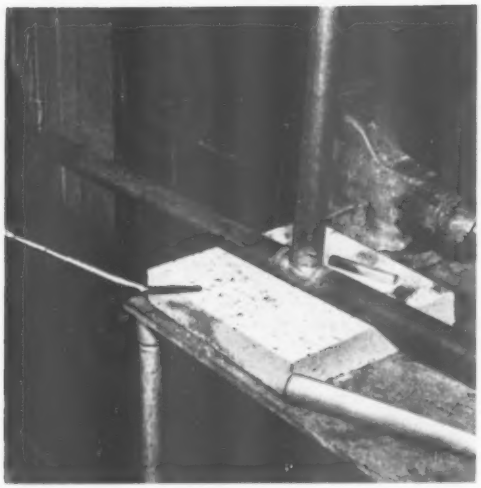


Fig. 11 In making structures of pipe, push the "branch" into the "header" as far as it will go

Fig. 12 The easiest way to make a turn in pipe is to cut and weld it. You can make turns of any angle

BRANCH AND HEADER CONNECTION

Here's another simple type of joint you will make. This is called a T or branch and header connection. Place the branch on the header and mark the hole on the header with a piece of chalk or soap stone. Make center punch marks and cut the hole in the header. If this connection is for a ladder, shed frame or a piece of equipment, push the branch into the hole as far as you want. Of course, if you are running a water line with the pipe you can't block the inside of the pipe. Then you will have to place the branch pipe into the hole, mark the end of the branch and trim off the branch with your cutting attachment. Remove the slag and clean both pieces with a wire brush and steel wool.

Place the branch into the hole again and line up the inside edges of the branch and header. This is called a fillet weld. The important thing to remember is to concentrate most of the heat on the header pipe. The branch will be heated by radiation.

Make three tack welds, as shown in Fig. 11 and let the tack welds cool slightly before you start the final weld between two of them. You must now bridge across two surfaces that are at an angle to each other. It's easier if you can turn the work often so that the vee formed by the sides of the two pieces of pipe is always in the flat position. Be sure to melt both the header and branch pipe metal before you add molten metal from the welding rod. Don't let the welding rod metal drip into the molten puddle. Always place the rod in the bottom of the puddle when you add metal. Remelt the tack welds as you come to them or the joint will be weak. When the weld is finished, let the pipe cool before you use it.

These welds are basic welds for all pipe work. Of course, the pipe system may have many turns and connections in it, but all the welding should be done in the same way. That's why it's a good idea to learn to do these welds before you attempt to lay out jobs.

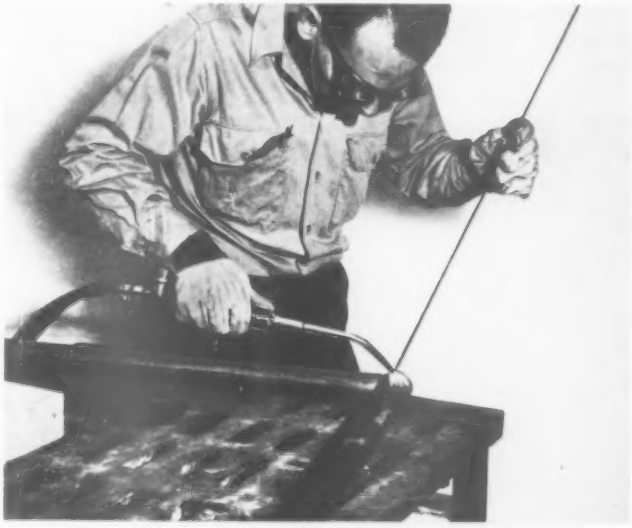


Fig. 13 Make one cut and rotate one piece 180°. Here a right-angle turn was made in this way

CHANGING DIRECTION OF PIPE

Whenever you build anything from pipe—a water line, a hat and coat rack—you want to make square or curved turns, and branch connections. There are several ways to make turns in pipe without cutting it. If the pipe is less than 2 in. in diameter you can fill he pipe with sand, plug the ends, then heat and bend the pipe. You'll get a smooth clean curve. If the pipe is larger than 2 in. in diameter you can make wrinkle-bends. In wrinkle-bending you heat a narrow band $^3/_4$ of the way around the pipe and apply a bending pressure to the pipe. The number of heated bands depends upon the angle required. When the metal gets soft the pipe actually wrinkles. Another simple way to make a turn is to cut the pipe and then reweld it.

Welding fittings are also available for making turns in pipe. You can get 90° elbows, 180° returns, 45° elbows, tees, caps and several types of reducers. With these fittings all you have to do is weld them to the straight lengths of pipe to form any type of bend.

For many of the welding jobs in pipe, both for making structures and installing pipe lines, bronze welding is just as satisfactory as fusion welding with steel rod—and easier and quicker to do. Your welding supply jobber will help you choose the best welding rod for both steel and bronze welding.

Welded Carriers Keep the Barrels Rolling

HOLLOW tubing, $^5/_8$ in. in diameter, rivets and a small hanger are the easily obtained materials needed to turn out a barrel or fiber drum carrier to be attached to a conveyor.

First a 3-ft. length of tubing was shaped on a tube bending machine and another length, to be used as a cross bar, was bent at an angle at each end.

ARC WELDING USED

The cross bar was then arc welded to the shaped tubing with $^1/_8$-in. No. 90 Flectrodes using a machine current setting of 125 amp., straight polarity The metal hanger was welded to the top of the carrier with the same type of electrode and current.

To protect workers' fingers from rough burrs, rivets were next welded into the open ends of the tubing forming the carrier and the cross bar.

The purpose of the carrier is to provide a convenient assembly line for finishing barrels or fiber drums. The barrel fits in the carrier which is attached to a moving conveyor. When the carrier reaches the end of the line, the welded cross bar is tripped by an obstruction and the barrel rolls off.

Tubing lends itself to many similar items that can readily be constructed in welding shops.

Fig. 1 Welding cross bar to barrel carrier

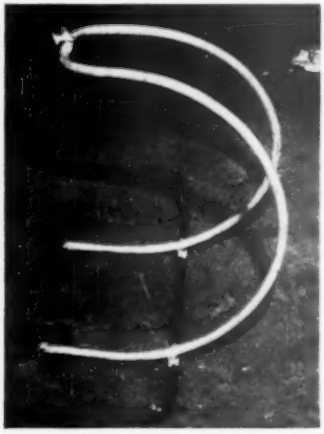


Fig. 2 Completed barrel carrier

Designing for Welding—Part VIII—Seam Welding

by Wallace A. Stanley

FIGURE 7 shows various types of special wheels that can be used for welding special shapes. Figure 7 (*A*) is a condition sometimes used in the industry where a channel section is welded to flanged sheets, or a small circular bottom is seam welded to a round container. Figure 7 (*B*) shows the use of a special wheel on the bottom to weld a dished head in a cylinder. This type of joint produces a satisfactory weld, but designs of

Wallace A. Stanley is Application Engineer, Progressive Welder Co., Detroit, Mich.

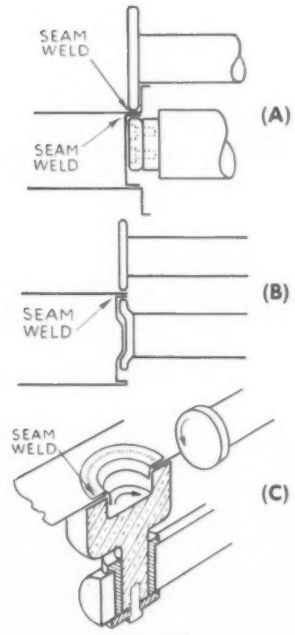


Figure 7

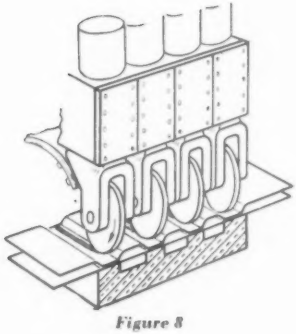


Figure 8

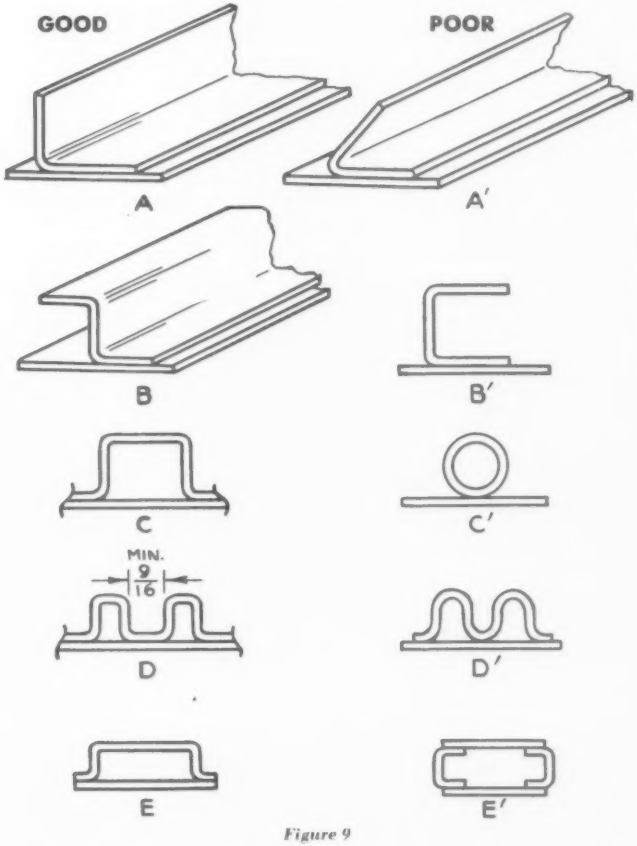


Figure 9

this type should be avoided due to the excessive wheel maintenance cost. Figure 7 (*C*) shows the welding of circular cup-shaped flange to a sheet.

In this case, the upper wheel rotates the lower cup to complete the weld. This design is used in welding necks to various types of containers, etc.

Figure 8 shows the welding of corrugations to a sheet where two or more rows of seam welds are made simultaneously. In this type of welding upper rolls move on an overhead carriage, while the lower bed and work remain stationary. Refrigerator evaporator trays, aircraft wing structures, high-strength flooring, retaining shells, etc., are applied to this type of welding.

Figure 9 shows good and poor practices for seam welding joint design. Some of these, like joints A′, B′, C′ and E′ are hard to get to weld although they could be seam welded. A′ would require angle-set wheels. B′, C′ and E′ would require traveling mandrels or other special forms of electrode shapes and tooling instead of lower wheel. The contact areas of C′ and D′ also are not adequate where a high-strength weld is desired. D′ would also require a very narrow wheel. Thus, although some poorly designed joints *can* be seam welded, because of their cost of special tooling and the maintenance of these tools, it would be more economical and practical to change over to some other joint design.

Butt-Welding Structural I-Beams

The importance of proper welding sequence is emphasized, method of estimating contraction is indicated

by F. Lang

MANY industrial buildings exhibit heavy continuous butt-welded structural I-beams. To weld such an I-beam is troublesome, when the welding sequence is not correctly performed. It is necessary to specify the sequence and the welding has to be done according to specification. The edges to be joined by welding were beveled by flame cutting, cleaned by grinding for double-V welds in both the web and flange, as shown in Fig. 1 and by details in Table 1.

F. Lang is with the São Paulo Tramway, Light and Power Co., Ltd., São Paulo, Brazil.

Table 1—The Applied Welding Sequence

Flange thickness	*Electrode size, mm.*	*Current amp.*	*Bead No.*	*Remarks*	*Sketch*
30 *m/m.*	4 EV2	160	1		
	5 EV2	220	2, 3	Turned over 1st Chipped rootbead F_1	
	4 EV2	160	4		
	5 EV2	220	5, 6		
	6 EV2	270	7		
	6 EV2	270	8	Turned over 2nd Turned over 3rd	
					Detail 1
Web thickness 16 m/m.	4 EV2	160	9		
	6 EV2	220	10	Turned over 4th	
	4 EV2	160	11		
	5 EV2	220	12		
	6 EV2	270	13		
					Detail 2
Flange thickness 30 m/m.	4 EV2	160	1 ft.		
	5 EV2	220	2 ft., 3 ft.	Turned over 1st Chipped rootbead F_2	
	4 EV2	160	4 ft.		
	5 EV2	220	5 ft., 6 ft.		
	6 EV2	270	7 ft.		
	6 EV2	270	8 ft.	Turned over 2nd Turned over 3rd	
					Detail 3

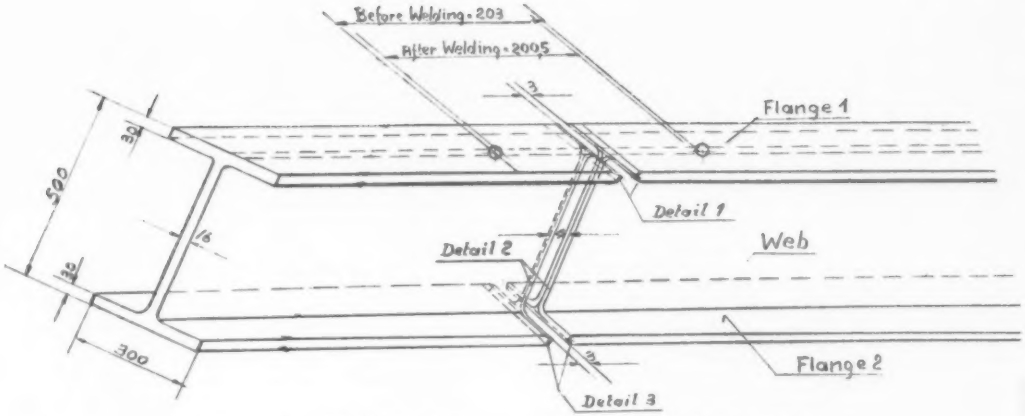


Fig. 1 A welded I-beam with measuring points before and after welding

It is well known that the heavier sections should be welded first and then the thinner parts of a welded construction.

In the following manner many I-beams (IP50) have been welded without cracking. The performed welding sequence is tabulated in Table 1, and can be seen on sketch.

The joint was heavily tack welded. First, the flanges were welded, and then the last beads on the web. According to the thickness of the flanges, a space of 3 mm. was made. The edges of the web were cut off 0.5 mm., resulting in a gap of 4 mm., due to the free movement of shrinkage in the entire joint. The located measuring point on each side of the joint has a distance of 100 mm. The over-all distance, including the space of the flange was 203 mm. before welding. Afterward the I-beam was completely welded, the distance was measured and showed a length of 200.5 mm., so that a contraction of 2.5 mm. took place. It seems to be in accordance with the formula:

$$R_n\, 0.1716\, \frac{s}{e} + 0.0121b$$

for covered electrodes[1], or

$$R_t 0.1716 \times \frac{360}{30} + 0.0121 \times 25$$

or

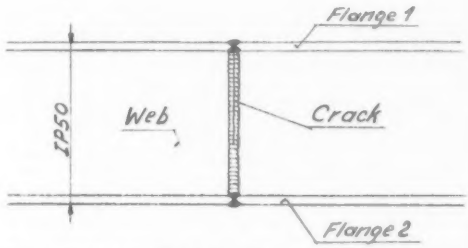


Fig. 2 Crack into the web, when the welding sequence is wrong

$$2.059 + 0.302 = 2.361 \text{ mm.}$$

This formula will also be acceptable for heavy tack-welded joints, and particularly with a short length of a double-V butt joint.[2]

The applied welding sequence was satisfactorily established, both parts, as well as the flange as the web has not failed.

On the contrary, starting the weld in the web and subsequently welding the flange, resulted in cracks in the web, while welding the flange (Fig. 2).

References

1. Guyot, F., "A Note on the Shrinkage and Distortion of Welded Joints," The Welding Journal, 26 (9), Research Suppl., 519-s to 529-s (1947).
2. Malisius, R., *Die Schrumpfung geschweisster Stumpfnaehte.*

the AMERICAN WELDING SOCIETY

activities • related events

Board of Directors Meeting

A Board of Directors meeting was held in the Hotel Statler, Cleveland, Ohio, on Friday, May 13, with the following in attendance:

Board Members: D. Arnott, J. J. Chyle, D. H. Corey, R. S. Donald, O. B. J. Fraser, J. H. Humberstone, T. M. Jackson, T. B. Jefferson, C. I. MacGuffie, L. S. McPhee J. F. Maine, F. L. Plummer, H. W. Pierce, G. N. Sieger, J. B. Tinnon, J. R. Wirt.

Staff Members: J. G. Magrath, Executive Secretary; M. M. Kelly, Secretary and F. J. Mooney.

By Invitation: M. S. Shane, Chairman of the Cleveland Section; C. T. Elder, Vice-Chairman of the Cleveland Section, and J. F. Wagner, Secretary of the Cleveland Section.

Call to Order

Mr. Fraser called the meeting to order at 9:15 A.M. A warm welcome was given to President Sieger on his return from several months' absence because of illness, and to the officers of the Cleveland Section, who were invited to participate in this meeting.

By-Law Amendments

Proposed revisions to the By-Laws, which were prepared by the Constitution and By-Laws Committee, approved by the Executive Committee on March 7, 1949, and published in the May 1949 WELDING JOURNAL, were considered, as were also two further revisions prepared by the By-Laws Committee, and distributed to the Board at the May 13, 1949 meeting.

After deliberation, all proposed amendments were approved for submittal to the voting membership.

Retirement of A.W.S. Secretary

Mr. Fraser reported that on recommendation of the Executive Committee at its meeting on Jan. 4, 1949, and endorsed by the Board of Directors at its meeting on January 21st, the position of "Secretary Emeritus" was created. The By-Laws Committee was requested to prepare a suitable By-Law covering this position and the Acting President, in consultation with legal counsel, was requested to prepare draft of agreement covering terms and salary. Consideration was given to the granting of a leave of absence with full pay to the retiring Secretary. These matters were considered further at a meeting of the Executive Committee of the SOCIETY on March 7, 1949, and on recommendation of the Executive Committee, the Board of Directors of the SOCIETY at its meeting on May 13, 1949, voted approval of: (*a*) By-Law amendment providing for the position of "Secretary Emeritus;" (*b*) appointment of M. M. Kelly to the position of Secretary Emeritus as of Oct. 1, 1949; (*c*) acceptance of agreement between A.W.S. and M. M. Kelly in respect to position of Secretary Emeritus, which agreement has been prepared in consultation with E. Holloway, A.W.S. legal counsel; (*d*) leave of absence to Secretary M. M. Kelly from period June 1, 1949, to Sept. 30, 1949.

Appointments

Assistant Secretary and Assistant Treasurer. On recommendation of the Executive Secretary with the endorsement of the Executive Committee at its meeting on Mar. 7, 1949, Francis J. Mooney was appointed to position of Assistant Secretary and Assistant Treasurer, retroactive as of May 1, 1949.

Assistant Technical Secretary. On recommendation of the Technical Secretary with the endorsement of the Executive Secretary and the T.A.C., J. I. Medoff was appointed to the position of Assistant Technical Secretary.

Service Manager and Secretary of Section Advisory and Membership Committees. On recommendation of the Executive Secretary and with the endorsement of the Executive Committee at its meeting on Mar. 7, 1949, Edward Krisman was appointed to the position of Service Manager to replace Mr. Mooney, who has been elevated to the position of Assistant Secretary and Assistant Treasurer.

Finances

In reviewing audited report on financial status of SOCIETY as of Mar. 31, 1949, the Chairman of the Finance Committee drew attention especially to results of past six months' operation, which showed an excess expense of approximately $6716 over income. He pointed out that the earned dues income for the past six months of the current fiscal year fell short approximately $8000 of that anticipated in the budget from increased membership dues; JOURNAL expenses for the first six months exceeded income by approximately $503, largely because of failure to realize budgeted increased advertising revenue; anticipated revenue from *Welding Metallurgy* and *Welding Handbook*, third edition, has not been forthcoming because of delayed publication. To prevent ending the fiscal year with a loss greater than that anticipated in the 1948–49 budget, the Finance Committee looks to:

(*a*) The Membership Committee to encourage the Section Membership Committees and Officers to continue their promotional efforts throughout the spring and summer months, particularly in interesting top industrial management in the SOCIETY;

(*b*) The Publication Committee to reduce JOURNAL expense by reducing the number of printed pages in the JOURNAL sufficiently to live within the JOURNAL budget;

(*c*) The Handbook and Educational Books Committee to expedite publication of the third edition of the *Handbook*, the *Welding Metallurgy* and other educational books under consideration.

Mr. Donald reported that the Publication Committee has been approached and agreed to comply with request of Finance Committee to do all in its power to bring the expense of THE WELDING JOURNAL under the total receipts for the JOURNAL. The Editor anticipated such a request, and with full approval of the Committee, has been keeping expenses down wherever possible. The Committee now proposes to cut THE WELDING JOURNAL some eight pages a month during May to August, inclusive, resuming normal operations in September and October as these issues are the Annual Meeting numbers and must, of necessity, be quite large to include the Annual Meeting papers available for publication.

Mr. Magrath reported that the *Welding Metallurgy* was just off the press. Concentration is now on sales of the book. He further reported that the Handbook Committee is doing its utmost to complete the *Handbook* text in the hopes of having proof copy on exhibition at the 1949 Annual Meeting and shortly thereafter to have the book ready for distribution.

Membership. Mr. Mooney reported that as of Apr. 30, 1949, the membership was 7192, consisting of 116 Sustaining 3033 Members, 3921 Associate, 113 Student and 9 Honorary Members. During the month of April the SOCIETY showed a net gain of 87 members. He said that during the month of April, the Detroit Section sent in membership totaling $1000 and secured six Supporting Company enrollments.

On recommendation of the Chairman of the Finance Committee, the auditor's statements showing status of the SOCIETY at the end of the first six months of the current fiscal year, Mar. 31, 1949, were accepted.

1949 Annual Meeting Budget

The proposed budget for the 1949 An-

Cut Costs with the Team of DC and AC Arc Welding

By Jack Manternach, Jr., Production Manager
The Heltzel Steel Form & Iron Co., Warren, Ohio

Jack Manternach, Jr.

In our search for better welding and lower costs, we have made a careful analysis of the relative merits of DC and AC equipment to get greatest possible welding speeds and utmost satisfaction of our welders.

Our manufacturing and fabricating work involves material of a wide range of thicknesses . . . steel, alloys and some non-ferrous metals . . . small parts and huge assemblies. Because of this wide variety of jobs, we find DC arc welding basic for our requirements.

However, there are some applications where arc blow is severe, and here AC welding enables us to use higher currents and get faster production.

Introduction of the Lincoln "Fleetwelder" has made AC welding acceptable to our men. Its safe open circuit voltage, deep penetration qualities and easy current adjustment have led us to install a number of these machines for the jobs where arc blow is severe.

We find it is helpful to have the unbiased advice of the Lincoln Welding Engineer to decide the extent to which we use AC welding as a supplement to our DC welding.

Fig. 1. This 400-amp. "Shield-Arc" is typical of many Lincoln DC welders used for bulk of work at Heltzel. A number of AC "Fleetwelders" such as shown at left are used on heavy jobs where arc blow is severe.

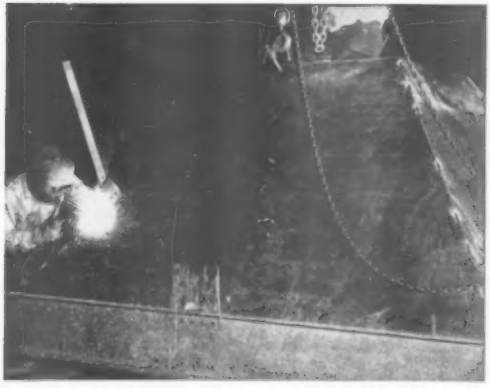


Fig. 2. Fabricating hopper for aggregate plant with "Shield-Arc" DC Welder and 3/16" "Fleetweld 7" Electrode.

Fig. 3. Fabricating a machine base. For joints in corners, such as these, arc blow makes AC "Fleetwelders" advantageous.

The above is published by **THE LINCOLN ELECTRIC COMPANY** *in the interests of progress.*
Write for DC "Shield-Arc" Bul. 459 and AC "Fleetwelders" Bul. 366. The Lincoln Electric Company, Dept. 98, Cleveland 1, Ohio.

nual Meeting was accepted as submitted with exception of $845 figure for furnishing machines and operators for the technical sessions at the Annual Meeting.

Inasmuch as motion picture machines and slide projectors can be secured at little or no cost by the Cleveland Section Convention Committee representatives, the anticipated expenditure for furnishing machines was reduced to $345 and approved by the Convention Committee Members.

Restoration of Welding Handbook as Membership Benefit to Members Enrolled in Member Grade

On recommendation of the Executive Committee, it was voted to revoke action taken in February 1948 by the Board of Directors in limiting the free distribution of the third edition of the *Welding Handbook* to members enrolled in the Sustaining Member grade and to members enrolled in the Member grade who joined prior to and including Dec. 31, 1948. It was recalled that at time action was taken it was believed the *Handbook* would be published on or before Dec. 31, 1948, and the *Handbook* could be used as an inducement to Members joining prior to Dec. 31, 1948.

Awards Committee Report

1948 Samuel Wylie Miller Memorial Medal. Report of the Awards Committee on selection of A. G. Bissell as recipient of this Medal was accepted.

Nomination of National Officers

The Board approved recommendation of the Executive Secretary that the 1949 National Nominating Committee be appointed a Special Committee with scope to prepare guide for Sections, areas or groups in recommending persons for nomination areas or groups in recommending persons for nomination to national officers.

G. S. Herren Memorial Resolutions

Appointment by Acting President Fraser of Special Committee, consisting of R. R. Grant and C. B. Voldrich, for purpose of drawing up suitable memorial resolutions for G. S. Herren, deceased, was confirmed, and by vote of the Board the resolution prepared by this Special Committee was adopted for the records and transmittal to the family of Mr. Herren. A vote of thanks was extended to the Resolution Committee.

Progress Report on 1949 Annual Meeting

M. S. Shane, Chairman of Convention Committee, stated that no serious handicaps were indicated in any phase in planning the 1949 Annual Meeting and that success is assured. Physical effort only is required.

Convention Committee met in the Hotel Statler, Thursday, May 12th, and progress reports covering the major elements of budget, housing and meeting rooms, technical program, publicity, exhibits and President's Reception were discussed which indicated much work had been done and progress in excellent shape.

Mr. Shane reported as follows:

(*a*) Hotel Housing: Hotel Cleveland reported 80% of room applications have already been acknowledged and in a week the other 20% will be. Hotel Cleveland has allotted A.W.S. 535 rooms in place of 500 as originally contracted for. They will turn over to Housing Bureau about 100 requests. Hotel Cleveland is sending letters explaining their action and that Housing Bureau will apportion rooms at its meeting to be held June 17th.

(*b*) President's Reception. The major decision of the Convention Committee was to abandon the Annual Dinner previously scheduled for Thursday evening and the President s Reception, Sunday afternoon, and combine these affairs into one concerted effort, to be known as the President's Reception and to be held on Tuesday evening, at about 8 P.M.; the Reception to consist of a buffet dinner, pay-as-you go bar, and then dancing, music, etc. The subscription price will be in the neighborhood of $4 per person, including tax. A.W.S. will underwrite a portion of this event in the amount of $450 as this sum was budgeted for the President's Reception, previously scheduled for Sunday evening.

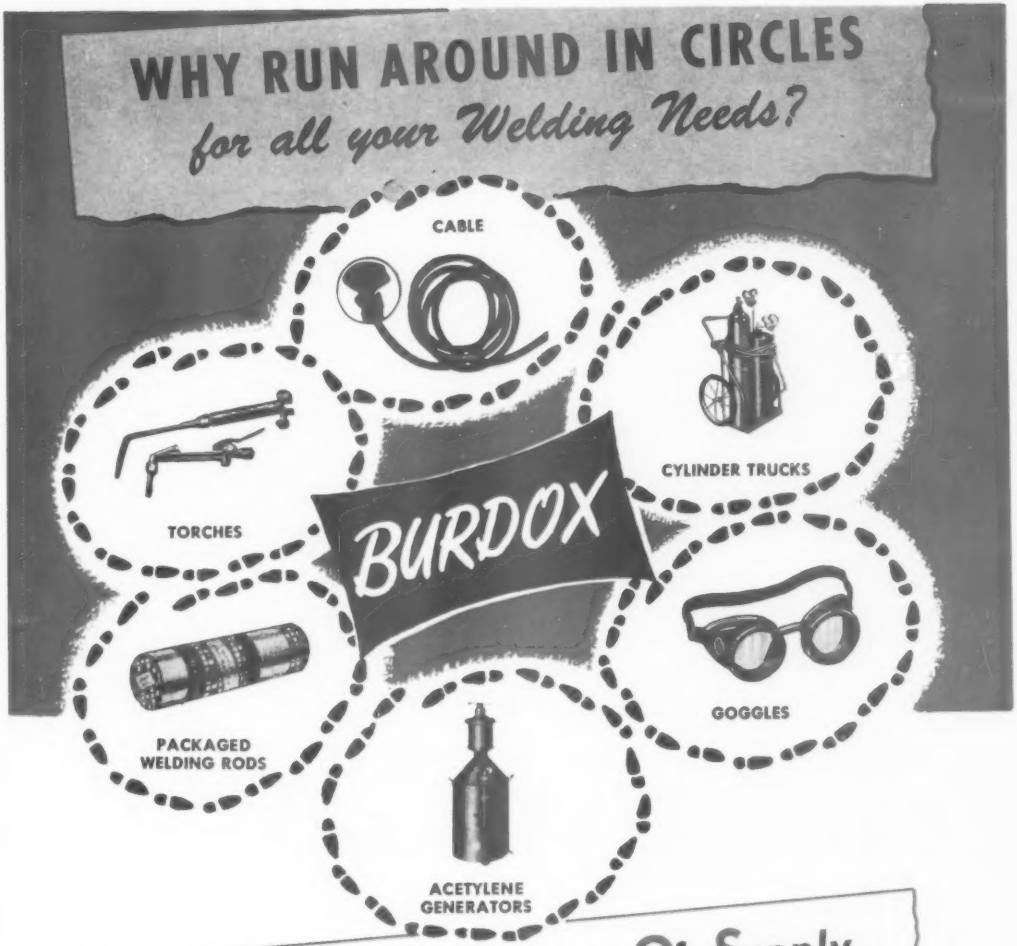
Report on Accomplishments of N.E.M.A. Welding Section

Joint N.E.M.A.-A.W.S.-W.R.C. Meeting. On Mar. 29, 1949, J. F. Lincoln, Chairman, N.E.M.A. Arc Welding Section, called a meeting of the Section at The Homestead Hotel, Hot Springs, Va. The Section Business Meeting followed on Mar. 30th. Representatives from A.W.S. and W.R.C. were invited and attended. In the opinion of the Executive Secretary

INDEX TO ADVERTISERS

Air Reduction Sales Co.	Outside back cover	The Lincoln Electric Company	777
Aluminum Company of America	781	The Linde Air Products Company	719
American Brass Company	Inside back cover	P. R. Mallory & Co., Inc.	717
American Chain & Cable	783	Metal & Thermit Corporation	716
Ampco Metal, Inc.	799	National Carbide Corporation	792
Anti-Borax Compound Company, Inc.	798	Oakite Products Inc.	796
Arcos Corporation	785	Page Steel & Wire Division	783
The Auto Arc-Weld Mfg. Co.	789	Revere Copper and Brass Incorporated	810
The Burdett Oxygen Company	779	Ruemelin Mfg. Co.	784
The Champion Rivet Company	797	Stulz-Sickles Co.	788
Dockson Corporation	796	Tempil° Corp.	780
Eastman Kodak Company	791	Tube Turns, Inc.	787
Eisler Engineering Co., Inc.	788	Tweco Products Company	Inside front cover
General Electric Co.	794 and 795	Union Carbide and Carbon Corp.	719
Hobart Brothers Company	715	Victor Equipment Company	720
The International Nickel Co., Inc.	802 and 803	J. H. Williams & Co.	796

WHY RUN AROUND IN CIRCLES
for all your Welding Needs?



use this single Source Of Supply to save yourself TIME and MONEY

To get "the most for the least" out of any welding or cutting job, standardize on BURDOX products. They are produced by welding men who know from experience how to give you the best results . . . in the quickest time . . . at the lowest cost! Every BURDOX product provides the latest improvements, and offers outstanding quality at prices that mean real savings to you. BURDOX products are handled by leading welding distributors. Get acquainted with the hundreds of items in the BURDOX Line by sending for free new 68-page catalog.

THE BURDETT OXYGEN CO.
Established 1920
3333 LAKESIDE AVENUE
CLEVELAND 14, OHIO

THE BURDETT OXYGEN COMPANY
3333 Lakeside Avenue, Cleveland 14, Ohio
Please send free copy of new 68-page catalog.

FIRM _____

NAME _____

ADDRESS _____

CITY _____ STATE _____

the meeting was beneficial and provided an opportunity for Members of each group to become better aware of each group's respective problems as well as to cooperatively seek a platform of common understanding which would be beneficial to the well being and progress of the Welding Industry. The President, or his Representative, and the Executive Secretary of A.W.S. and the Director of W.R.C. were extended an invitation by Chairman J. F. Lincoln to attend future N.E.M.A. Arc Welding Section Meetings.

Visitation of Sections

Following is J. G. Magrath's report on Section Activity:

"Since the previous Board of Directors Meeting, the following Section Cities and potential Section or Section-Division Cities have been visited by the Executive Secretary: "Detroit, Mich.; Buffalo, Olean and Rochester, N. Y.; Erie, Pa.; Roanoke, Va.; Cincinnati, Ohio; Louisville, Ky.; Longview and Dallas, Tex.; Phoenix, Ariz., Long Beach, Los Angeles and San Francisco, Calif.; Portland, Ore.; Seattle and Spokane, Wash. At Spokane his Section tour was interrupted by a requirement necessitating his return to New York City. He resumed Section activity as of this day, May 13th.

"New Section or Section-Division activation was either started or furthered at Olean, Roanoke, Longview, Dallas and Phoenix. Official activity will soon begin at Olean, Roanoke, Dallas and Phoenix. Section Officer and Executive Committee meetings were held at all other points named and plans made for each extending their membership and program activities. All Sections are working hard on the reduction of delinquency. Most are finding difficulty in securing new members, but continue their efforts. Detroit and Buffalo are outstanding in their campaign for new membership. Detroit, particularly, is outstanding in its success in selling industry individual membership through the Supporting-Company plan. All Sections are very favorable to the utilization of the new *Executive A.W.S. Brochure* for the purpose of interesting top management in SOCIETY activity and representative membership.

"Addresses were made by the Executive Secretary before regular membership or potential membership activation meetings at Rochester, Erie, Olean, Dallas, Phoenix, Los Angeles, San Francisco and Seattle, on the subjects 'It's Your Society' at the organized sections and 'THE AMERICAN WELDING SOCIETY' at the cities holding activation meetings.

"He attended the Purdue Welding Conference at Purdue University, Lafayette, Ind. No exhibit was held there this year, hence it was not heavily attended. The smaller attendance was select as were the papers given. Purdue is desirous that the SOCIETY join them officially in sponsoring the Purdue Welding Conference annually and assisting them in the program.

"He attended the Western Metals Congress at Los Angeles and the West Coast A.W.S. Technical Meetings held in conjunction with the Congress. Hugo W. Hiemke, Consulting Engineer, was Program Chairman and with the aid of E. O. Williams and others of Los Angeles, arranged and presented a very interesting and very well attended Technical Meeting Series. The exhibit portion of the Congress, in the Executive Secretary's opinion was very successful.

"Due to the requirement necessitating his prompt return to New York City, he requested Prof. G. S. Schaller, District Vice-President, to officiate for him at a Section Activation Meeting scheduled for Salt Lake City, Utah. Professor Schaller did so and as a result of his excellent work, a successful activation meeting was held, and we may soon expect to officially have a new Salt Lake City Section."

Expression of Thanks

President Sieger extended his thanks and appreciation to Mr. Fraser, the other national officers and to the Board of Directors for carrying on in his absence.

Expression of Sympathy

Sincerest sympathy was extended to Mr. Magrath in the loss of his wife.

Date, Time and Place of Next Meeting

It was voted to hold the final meeting of the 1948–49 Board of Directors in New York on Sept. 22, 1949, at 9:30 A.M.

Tempilstiks°

the amazing Crayons that tell temperatures

Simply mark your workpiece with the proper Tempilstik°. When the mark melts, the specified temperature has been reached.

Available in these temperatures (°F)			
125	275	500	1100
138	288	550	1150
150	300	600	1200
163	313	650	1250
175	325	700	1300
188	338	750	1350
200	350	800	1400
213	363	850	1450
225	375	900	1500
238	388	950	1550
250	400	1000	1600
263	450	1050	

$2 each

Also available in pellet or liquid form

A convenient method of controlling working temperatures in:

- WELDING
- FLAME-CUTTING
- TEMPERING
- FORGING
- CASTING
- MOLDING
- DRAWING
- STRAIGHTENING
- HEAT-TREATING IN GENERAL

FREE — Tempil° "Basic Guide to Ferrous Metallurgy" — 16¼" by 21" plastic laminated wall chart in color. Send for sample pellets, stating temperature of interest to you.

TEMPIL° CORP., 132 WEST 22nd ST., NEW YORK 11, N. Y.

We invite inquiries from reputable distributors interested in handling Tempil° products.

No other metal offers "built-in" brazing

It's called Alcoa brazing sheet . . . tough aluminum alloy clad on one or both sides with a layer of brazing alloy.

Result? Parts fabricated of this material need only be formed, assembled and heated to make a finished piece. Besides its exceptional economy, brazing sheet often permits assemblies not otherwise possible.

But that's not all to the aluminum brazing story. Many Alcoa Aluminum alloys can be brazed by conventional methods. Torch. Furnace. Dip.

You're missing a big production bet if you haven't considered brazing for your aluminum assemblies. And you're missing a lot of good technical information if you don't get a copy of Welding and Brazing Alcoa Aluminum. Ask your nearest Alcoa Sales Office or write ALUMINUM COMPANY OF AMERICA, 1933H Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA FIRST IN ALUMINUM

ALCOA ALUMINUM

INGOT • SHEET & PLATE • SHAPES, ROLLED & EXTRUDED • WIRE • ROD • BAR • TUBING • PIPE • SAND, DIE & PERMANENT MOLD CASTINGS • FORGINGS • IMPACT EXTRUSIONS
ELECTRICAL CONDUCTORS • SCREW MACHINE PRODUCTS • FABRICATED PRODUCTS • FASTENERS • FOIL • ALUMINUM PIGMENTS • MAGNESIUM PRODUCTS

NEWS OF THE INDUSTRY

Hobart Appoints New Distributor

Virginia Welding Co., 114–116 Virginia St., E., Charleston 1, W. Va., has been appointed distributor for Hobart Brothers Co. Managed by W. A. Rice, this firm distributes the full line of Hobart Welding Equipment, including d.-c. and a.-c. arc welders, accessories and electrodes— covering most of the counties in West Virginia.

Virginia Welding Co. was founded by V. S. Rice in 1917 and has been in its present location for 26 yr. This firm is one of the oldest welding supply houses in the State of West Virginia.

In addition to arc-welding equipment, they sell and service almost every item that is used in welding or in conjunction with welding.

Lincoln Electric Authorizes Construction of $8,500,000 Plant

The Lincoln Electric Co. on June 20th, according to James F. Lincoln, President, completed final arrangements with The Austin Co. of Cleveland for the immediate construction of an $8,500,000 plant to be erected in Euclid, Ohio.

The one-story manufacturing plant will contain over 850,000 sq. ft. of floor area on a 65-acre site on St. Clair Ave. between E. 222nd St. and Babbitt Rd. The new plant will be ready in 1950 for the transfer of all manufacturing operations from the present plant, which will be available for sale or lease at that time.

James F. Lincoln, in announcing plans for the new plant, said: "We are going ahead with our plans at this time because we feel that arc welding, as a relative newcomer to modern industry, has only scratched the surface in developing its potential contribution to the progress of all industry. More than ever, now, industry is turning to arc welding to find ways of reducing manufacturing costs while improving quality."

Tin Research Institute

John Ireland, Director, Tin Research Institute, London, England, announces the formation of Tin Research Institute, Inc., an American corporation devoted to providing free technical service to consumers of tin in the United States. The office of the new corporation, located at 492 W. Sixth Ave., Columbus 1, Ohio, will in the future handle all inquiries or requests for technical service, while a sponsorship will be maintained at Battelle Memorial Institute to handle new researches.

Technical experts are available for consultation and practical assistance either at the Tin Research Institute or at the consumers' plants.

A wide range of publications covering every important use of tin is available free of all charges. Inquiries are invited.

Robert J. Nekervis has been appointed Supervisor of Metallurgical Development and Robert M. MacIntosh has been appointed Supervisor of Chemical Development in the new corporation. Both have been associated with Battelle Memorial Institute for the last 8 yr., and served as Assistant Supervisors in the Nonferrous Division, handling problems related to tin.

The trustees of the new organization are Clarence D. Laylin, Dean Charles E. MacQuigg and Dr. Bruce W. Gonser, all of Columbus, Ohio.

Fresh-Air Welding Training

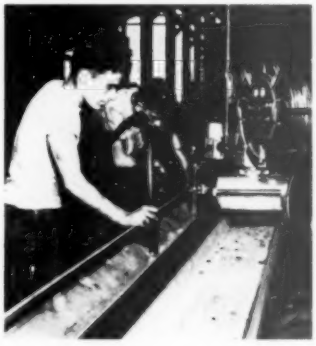
To better instruct and experience the students in the operation of gasoline-engine-driven arc welders, the Hobart Welding School, Troy, Ohio, has initiated an outside class in arc welding.

The school is located in the rear of the main welding school on a concrete surface and consists of eight 6-x 6-ft. welding booths and eight gasoline-engine-driven arc welders. The booths are welded pipe covered with flameproof canvas. A flameproof canopy protects the students from the hot sun.

All advanced welding students spend a full week of their welding training period out in the fresh air learning to operate gasoline-engine-driven arc welders. Each student has a booth and a welder for his own use during his outside training period. He learns how to start, stop and adjust the welding current of the machine, as well as general information on servicing the machine.

Structural Members Made to Order

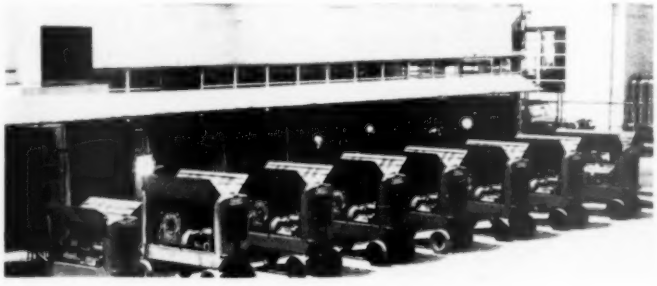
Many fabricators and contractors have found a simple and effective way to make the structural shapes they need when the rolled material is not available. Channels, I- and H-beams are easily made from flat plate or rolled angles using the "Unionmelt" welding process. The only other piece of equipment necessary to weld these sections is a fixture to support the assembled beam in position during welding.



Fabricating I-beam by "Unionmelt" welding

The first step in the process of building a beam is to oxygen-cut the pieces from flat plate. Next, the parts are assembled with clamps and tack-welded every 10 or 12 in. with manual arc welds. The assembled beam is then moved to the fixture and the long seams welded with the "Unionmelt" machine.

A beam 20 ft. long, like the one shown here can be completely welded in about an hour. The flanges are $^3/_8$ in. thick and the web is made of $^1/_2$-in. material. After the first weld is made, the beam is turned over and the second weld made with the equipment in the same relative position. The



PAGE WELDING ELECTRODES AND GAS WELDING RODS

WELDING STAINLESS?

○

TO RESIST WHAT?

HEAT?
COLD?
IMPACT?
BENDING FATIGUE?
CORROSION?
WHAT **KIND** OF CORROSION?

○

NOW ONE MORE QUESTION:

Are you using the best electrode or rod for your purpose?

If you're not too sure, get in touch with your PAGE distributor. Either he knows or he can find out from the PAGE Field Service Man. And the PAGE distributor has a wide selection of Page-Allegheny Stainless Steel rods and electrodes, so that he can give you the one that will serve you best.

ACCO

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Pittsburgh, Portland, San Francisco, Bridgeport, Conn.

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

TRADE MARK

Get in touch with your PAGE Distributor

beam is then turned end for end and the third and fourth welds made in the same manner. The welding speed for this operation is about 25 in. per minute.

Fillet welds for the I- and H-beams require no backing when the web is positioned at an angle of about 30° from the vertical. With the beam in this position and a fairly close fit-up, the flange itself supports the fluid weld puddle. The positioned fillet welds are deeply penetrated, the second weld penetrating into the first so that the strength of the welded beam is comparable to that of a rolled section.

Low labor cost per foot of weld makes it possible to produce special shapes or even standard forms by this process at costs that are considerably lower than for any other type of fabrication. In fact, some contractors have found it to their advantage to stock only the sizes frequently used and to make up the other sizes as required. This practice saves considerable investment as well as storage space.

Two Million Pound-Inch Torsion Testing Machine

A two million pound-inch torsion testing machine, believed to be the world's largest and accommodating specimens 4 ft. and 4 in. in diameter and 16 ft. long, has been proof-tested at the Fritz Engineering Laboratory of the Civil Engineering Dept. of Lehigh University.

Designed to study the torsional behavior of structural members such as plate and box girders, the testing machine is capable of handling full-sized bridge sections, twisting them through any desired angle. The machine itself is approximately 9 ft. high and 25 ft. long, with a gross weight of 15 tons and a center line 46 in. above floor level.

A year in construction, the machine was financed largely by the Lehigh University Institute of Research and the Pennsylvania State Highway Dept., with incentive resulting from the sponsorship at Lehigh of a full-time fellowship by the Research Corporation of New York City.

According to Prof. William J. Eney, head of the Department of Civil Engineering, the initial design studies were made by Dr. Knud-Endre Knudsen, former research fellow at the Fritz Laboratory, and by Dr. Bruce G. Johnston, director of the Laboratory, with translation and construction under the supervision of Fu-Kuei Chang, research fellow in charge.

Operation of the machine is described by Dr. Johnston as comparatively simple. One end of the section under test is fastened to the drum and the other end to a stationary part of the machine. The drum is turned by a force supplied by a large press through a belt-and-pulley arrangement, with power supplied by a small electric motor. An aluminum tube mounted with electrical resistance strain gages is inserted at one end of the specimen to measure the applied torque accurately. Arrangement is also made to enable the specimen to shorten during the twist without developing appreciable longitudinal stresses.

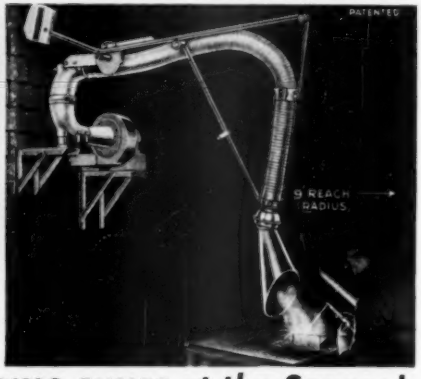
Two Million Pound-Inch Torsion Machine Being Tested at the Fritz Laboratory, Lehigh University

It is expected that the new Lehigh testing unit will provide needed information concerning the torsional strength of riveted and welded built-up girders where fundamental data do not equal that of rolled beams. The torsional consideration is of particular importance, for example, in the critical period of initial erection of railroad girder bridges.

Industrial cooperation played a notable part in the construction of the testing machine, with the Aluminum Company of America and the John A. Roebling's Sons Co. contributing materials, while the Lehigh Structural Steel Co. donated the first series of test specimens. The Bethlehem Foundry & Machine Co. contributed to the fabrication of welded and machine parts which could not be made directly at the Laboratory, while the Bethlehem Steel Co. socketed the wire ropes and furnished part of the steel. Bearings were furnished at cost by the SKF Co. and torsion dynamometers were made under license of the Baldwin Locomotive Corp.

RUEMELIN Fume Collector

(Above) Welding without ventilating snout. Note smoke clouds and poor vision. Gases and heat surround operator's helmet.



(Right) Collecting fumes with a Ruemelin Fume Collector.

REMOVES WELDING FUMES *at the Source!*

Solve your welding fume problem efficiently by installing Ruemelin Welding Fume Collectors. They produce a powerful suction that removes smoke, gas and heat at the source. Guards employee health, resulting in less welder fatigue. Clears shop air with minimum heat loss. Covers maximum welding area vertically, horizontally and by circle swing. Made in 9 ft. and 15 ft. reach sizes. Shipped assembled, easy to install. Thousands in practical service. Free engineering service for your installation.

Write for our New Bulletin 37-D and list of users — just off the press.

RUEMELIN MFG. CO.

MANUFACTURERS AND ENGINEERS
SAND BLAST AND DUST COLLECTING EQUIPMENT
3881 NORTH PALMER STREET • MILWAUKEE 12, WISCONSIN, U. S. A.

ARCOS QUALITY CONTROLS

yield dividends in stainless welds

Every Arcos electrode is the product of careful testing and retesting during development, followed by the close adherence to specification for raw materials, and very strict application of quality controls in manufacturing.

THAT IS WHY Arcos electrodes, in the hands of a competent welder, give consistently sound, trouble-free welds.

THAT IS WHY Arcos electrodes deposit weld metal physically, chemically and metallurgically right for the job at hand.

THAT IS WHY every day of welding with Arcos electrodes *yields maximum production*. Costly non-productive time, chipping and rewelding or repairing weld failures is eliminated.

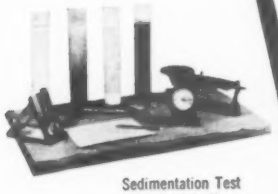
These are the reasons why the pound price of Arcos electrodes is not a true measure of the value of the welds developed from them.

•

Use Arcos quality controlled stainless electrodes to keep your weld costs low.

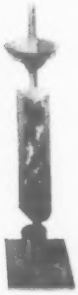
•

Viscosity Test



Sedimentation Test for Particle Size

Colorimetric Analysis of Steels

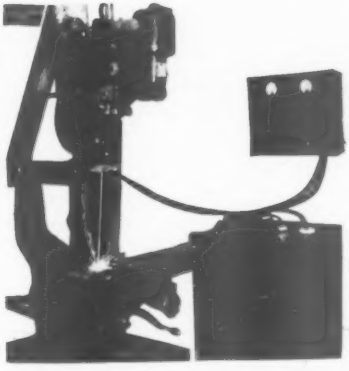


Bulk Test for Coating Materials

Ferro-Alloy Gassing Test

Eccentricity Test

Screen Test for Particle Size



Automatic Welding Machine

ELECTRODES • COILED WIRE • BARE ROD

PERSONNEL

Tebben Forms New Company

John D. Tebben announced the opening of a new company to do consulting work in engineering sales and industrial relations.

Mr. Tebben has been active in the metallurgical field for many years, and is nationally known in the electrical, aviation and resistance-welding industries. He was formerly general sales manager for the P. R. Mallory Co., and vice-president of the S. M. S. Corp. During the war, Mr. Tebben was a colonel in the Air Corps, stationed at Wright Field, Dayton, Ohio, as chief of the Aircraft Production Branch.

Active in many engineering societies, Mr. Tebben was a former vice-president of the AMERICAN WELDING SOCIETY, and past-chairman of both the Detroit and Indiana sections. He has also been an active member of both the Society of Automotive Engineers and the Engineering Society of Detroit.

The company's headquarters will be at 20869 Mound Rd., Detroit, Mich.

Lorch Made Branch Manager

Victor Equipment Co. announces the appointment of Charles Lorch as Branch Manager of its Chicago Office, located at 1312 W. Lake St., Chicago 7, Ill.

Mr. Lorch was graduated from Illinois College, Jacksonville, Ill., in June 1937, and worked as salesman for the Shippers Fuel Corp., Chicago, from September 1937 until September 1941. Joining Victor in 1942, Mr. Lorch advanced rapidly from the position of clerk to District Purchasing Agent and Office Manager for Victor's Southern California District with headquarters in Los Angeles.

Northacker Honored

Alfred A. Northacker, Assistant Purchasing Agent, the M. W. Kellogg Co., New York, N. Y., was elected and installed as Chairman of the Executive Board of the Metropolitan Purchasers' Assistants Club of New York City, at their annual meeting, held at the Midston House Hotel, on June 14th.

Prior to his election to the association's highest office, Mr. Northacker served two years as its president.

In addition to being a member of the above organization, he is an active member of the AMERICAN WELDING SOCIETY, American Society of Metals and the Office Executives Association of New York.

Alfred A. Northacker

With the Kellogg Co. since 1936, Mr. Northacker handles the purchase of pressure vessels and heat transfer equipment.

Other officers elected were: L. N. Read, Purolater Products, Inc., President; J. J. Sharkey, Culbert Pipe & Fittings Co., Vice-President; L. W. Skillman, Consolidated Railroads of Cuba, Secretary; and R. O. Condit, American Oil & Supply Co., Treasurer.

Belmont Smith Made President

Belmont D. Smith has been newly elected President and General Manager of Industrial Overlay Metals Corp., manufacturers of the well-known line of Bergstrom hard-surfacing electrodes.

Mr. Smith has been actively engaged in the welding field, both gas and electric, since 1926 and has gone through all stages of the welding field from welder, salesman, service engineer, field engineer in developments, sales manager, and vice-president, to his present position.

Mr. Smith has been with the present company for 5 yr., starting when it was the Bergstrom Alloy Corp. of Los Angeles and Reno, Nev. He went East in 1945 to make his headquarters in Chicago as field engineer, covering the Eastern United States.

Mr. Bergstrom, former President of the Bergstrom Alloys Corp., having other interests on the Pacific Coast, wished to be relieved of his active position, so a new corporation, Industrial Overlay Metals of Eaton, Ohio, was formed to take over his interests. Mr. Smith is major stockholder and President of this corporation. He is a member of the AMERICAN WELDING SOCIETY.

A.S.M.E. Honors D. S. Jacobus and C. A. Adams*

* Taken from June 1949 issue of *Mechanical Engineering*.

The Boiler Code Committee of the American Society of Mechanical Engineers honored two of its distinguished members, D. S. Jacobus and C. A. Adams, at a testimonial dinner on Apr. 7, 1949, at the Astor Hotel, New York City. More than 85 members of the main committee and its subcommittee, with their wives, were present.

E. G. Bailey, Fellow and past-president A.S.M.E., presented to Dr. Jacobus and Dr. Adams a special scroll signed by their associates in recognition of their contributions to the committee and the American Society of Mechanical Engineers.

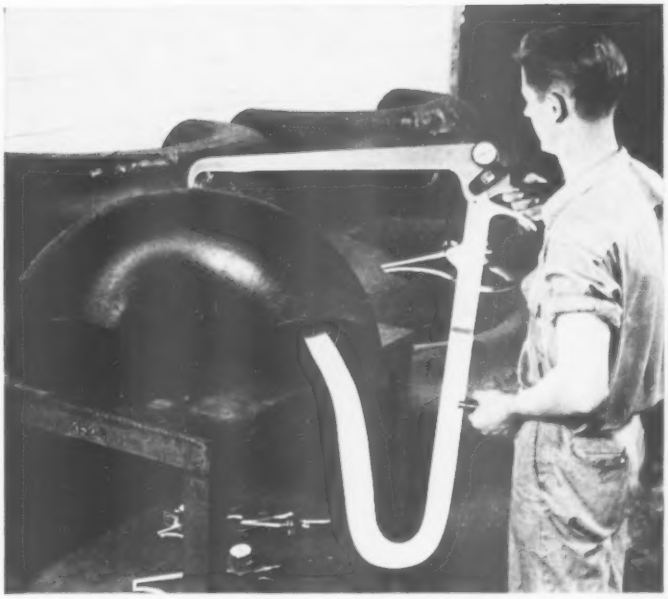
Speaking for the A.S.M.E., C. E. Davies, secretary A.S.M.E., called the occasion epoch-making in the history of the Society. "Tonight," he said, "the Boiler Code Committee and the Society are paying tribute to two men who have made one of the most important contributions to our work that I think has ever been made. I think of the A.S.M.E. stamp on a boiler as a mark of integrity, of honesty of mind, of objectivity of viewpoint, and to me the gentlemen we are here to honor tonight typify those three qualities, without which the Boiler Code cannot continue."

Among the associates who paid tribute to the two men were E. G. Bailey, J. H. Deppeler, C. O. Myers, C. W. Obert, H. LeRoy Whitney, W. H. Boehm and A. G. Pratt.

Dr. Adams joined the A.S.M.E. in 1917 and became a member of the Boiler Code Committee in 1934. In addition to serving on the Main Committee, he has been a member of the Subcommittee on Unfired Pressure Vessels, and the Committee on Welding. He has been chairman of special committees on radiographic examinations of welded joints, alloyed and high-tensile steels for welded pressure vessels, and approval of new materials.

For nearly 50 yrs. Dr. Adams taught at Harvard University and was a consultant on high-frequency induction heating, welding and gas explosions. After serving on the National Research Council in various capacities during World War I, he organized the AMERICAN WELDING SOCIETY and became its first president. Dr. Adams was also one of the founders and the first chairman of the American Engineering Societies Standards Committee, which is now the American Standards Association.

Dr. Jacobus is perhaps the only living member of the A.S.M.E. who was present at the organization meeting of the A.S.M.E. held in Stevens Institute of Tech-



Precision through Care in Tube-Turn welding fittings

"Mike" checks 'em all!

THE wall thickness of Tube-Turn welding fittings simply has to be right. Every single Tube-Turn welding fitting is micrometer-checked before being put on the market.

Instruments of exclusive design do the trick. They measure wall thickness at the center of an elbow or 180° return as easily, accurately as at any other point. Whether it's ten, a hundred, or a thousand, the Tube-Turn welding fittings you buy are properly matched to pipe of corresponding size —at the face and throughout the fitting. Cut a Tube-Turn welding elbow to any odd angle required. It still lines up.

This micrometer check for dimensional accuracy is a small part of the thorough scrutiny to which the finished Tube-Turn product is subjected.

More than thirty skilled inspectors check for true circularity, accurate center-to-face dimensions, uniformity of curvatures, soundness of outside and inside surfaces, wall thickness of butt ends, bevels, lands, and quality of machining.

And that's just a fraction of the total *care* involved in the manufacture of Tube-Turn welding fittings.

Perfection begins with the raw material which is checked for conformity to required chemical composition and physical properties. It must pass all pre-determined requirements before acceptance for production of Tube-Turn welding fittings. Special materials, of course, undergo special tests.

When you buy "Tube-Turn" you want good connections. That's what you get, every time.

TUBE TURNS, INC.

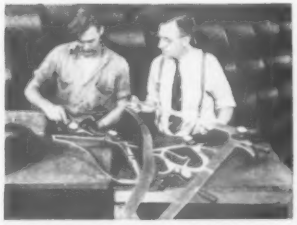
222 East Broadway, Dept. I, Louisville 1, Kentucky

District Offices at New York, Philadelphia, Pittsburgh, Chicago, Houston, Tulsa, San Francisco, Los Angeles

TUBE-TURN

tt

WELDING FITTINGS AND FLANGES



Five different-size gauges of exclusive design are used to check the wall thickness of every Tube-Turn welding fitting.

While one inspector checks the diameter of a 90° elbow, the other checks on perfection of inner wall.

Inspectors check the center-to-face dimension of a 20°-90° Tube-Turn welding elbow.

A part of the final inspection department. Here, Tube-Turn welding fittings undergo intensive instrumental and visual inspection.

nology in 1880. He became a member in 1889 and served as president in 1916. He began his boiler-code work in 1914 as a member of an advisory committee, and later became a member of the main committee. From 1917 to 1947 he was chairman of the Executive Committee, and from 1936 to 1941 chairman of the Main Committee. Dr. Jacobus helped to draft the Co-Ordinate Marine Boiler Rules, which were adopted by the Bureau of Navigation and Steamboat Inspection in 1935. He also helped to prepare the joint A.P.I.-A.S.M.E. Code for Pressure Vessels.

After graduating from Stevens Institute of Technology in 1884, Dr. Jacobus remained at the Institute to teach and to earn for himself an international reputation as a test engineer of power equipment. Before his retirement he was a consultant to the Babcock and Wilcox Company, New York, N. Y.

Amos Johnson Joins Stoody Sales

Amos Johnson, for many years a prominent figure in the welding industry of the northwest, has recently joined the field sales department of Stoody Co., manufacturers of hard-facing alloys.

Mr. Johnson has been assigned to assist Stoody distributors in Minnesota and the Dakotas. His home is in Minneapolis.

R. N. Chapin Appointed General Purchasing Agent

Air Reduction, manufacturer of industrial gases and welding equipment, has announced the appointment of Richard N. Chapin as general purchasing agent. Mr. Chapin will be located in Air Reduction's general offices, 60 E. 42nd St., New York 17, N. Y.

Mr. Chapin, a graduate of Rensselaer Polytechnic Institute, joined Air Reduction in 1935. From 1942 to 1945, he served as a buyer. From 1945 until his recent appointment, he was assistant purchasing agent. He succeeds Walter R. Clark, who resigned from Air Reduction to join U. S. Industrial Chemicals, Inc., as head of their purchasing department.

Mr. Chapin is a member of the AMERICAN WELDING SOCIETY.

Watson Becomes Vice President, S-M-S Corporation

Mr. G. N. Sieger, President of the S[illegible]-S Corporation, Detroit, Mich., has announced the election of Arthur M. Watson as Vice-President in Charge of Sales for the corporation. Mr. Watson is well known to the resistance welding industry, having formerly been associated with Sciaky Brothers in Chicago and, more recently, in resistance welding and metallurgical products as Sales Manager, Mid-Western Division of P. R. Mallory & Co., Inc. Mr. Watson is a member of the AMERICAN WELDING SOCIETY.

OBITUARY

Alexis Caswell

Alexis Caswell, secretary-treasurer of the Northwest Section from the time of its organization in 1937 until his retirement from business in 1947, died at his home in Minneapolis on June 3rd.

Mr. Caswell devoted 40 years to civic work and the industrial development of Minneapolis. In 1909 he became secretary of the Publicity Club, and when that organization joined the newly organized Minneapolis Civic & Commerce Assn. in 1911, Mr. Caswell served as its industrial secretary until 1919.

In 1919 he became secretary and business manager of the Manufacturers' Association of Minneapolis, Inc., which sponsored a number of affiliated organizations, among them the Northwest Section of A.W.S., and Mr. Caswell served as secretary-treasurer of each. The others were: North West Chapter, American Society for Metals; Twin City Chapter, American Foundrymen's Society; Twin Cities Chapter, National Association of Cost Accountants; Minneapolis Association of Sales Managers; Insurance Buyers Association of Minnesota; Twin City Foremen's Club; Northwest Foreign Trade Club and the Twin Cities Plastics Assn. In this way the various departments of an industry were served, each organization bringing to its members the latest technical knowledge in their respective fields. Mr. Caswell gave untiringly of his help and inspiration to the various groups and earned their unanimous characterization as a "grand gentleman."

In addition to his other civic work he was, during World War I, secretary of the Northwest Regional Resources and Conversion Section of the War Industries Board; during World War II, secretary of the Minnesota Industrial Salvage Committee until it became federalized, and secretary of the Occupational Safety Committee of the Greater Minneapolis Safety Council.

Mr. Caswell was born in Providence, R. I., in 1868, the son of Dr. Edward T. Caswell and Annie Baldwin Caswell, and the namesake and grandson of Dr. Alexis Caswell, early president of Brown University. He attended Brown and when his father died in 1887 he went west, first living in Milwaukee, Wis., and moving to Minneapolis in 1895.

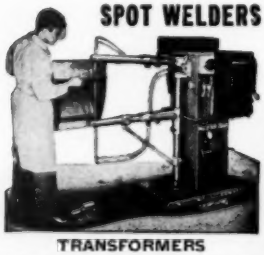
He is survived by his wife, Harriette, five children and 13 grandchildren; also by two sisters who reside in England.

Gustave Johnson

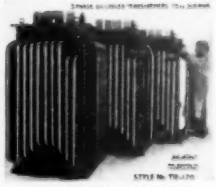
Gustave Johnson, 56, a leading welding engineer, died June 17th at his home in Milwaukee. He had been ill for three months. Mr. Johnson was technical and welding engineering supervisor for the Air Reduction Sales Co. He had been with that company for more than 30 years. He began his welding career in 1908 with the American Ox-Hydric Co. of Milwaukee, a subsidiary of the Falk Corp. He also worked for the Universal Oxygen Co. of Milwaukee and Sheboygan before going to the Air Reduction Sales Co.

Mr. Johnson was a director of the Milwaukee School of Engineering and a charter member of the AMERICAN WELDING SOCIETY. He was noted for his knowledge of welding and cutting processes.

Surviving are his wife, Anna, and son, Harold.



SPOT WELDERS OF ALL TYPES
SIZES 1/4 TO 300 KVA.
FOR MANUAL, AIR, MOTOR, OR ELECTRONIC OPERATION,
also BUTT, ARC, and GUN WELDERS



TRANSFORMERS
For Furnaces, Lighting, Distribution, Power, Auto Phase Changing Welding, and Special Jobs
AIR, OIL and WATER COOLED.
Sizes 1/4 to 200 KVA.

EISLER ENGINEERING CO., INC.
CHARLES EISLER, PRES.
779 South 13th St. (Near Avon Ave.) NEWARK 3, N. J., U.S.A.

WANTED!

Welders needing information on welding

11%-14% Manganese-Nickel Steel

WRITE FOR FREE LITERATURE

Ask to be put on our MANGANAL MARKETER mailing list.

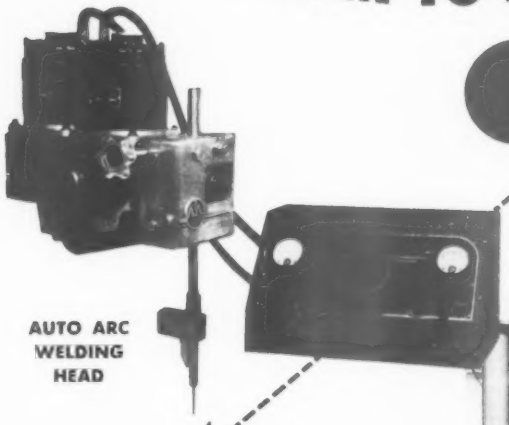
ROBERT BRAMLEY

STULZ-SICKLES CO.

134 Lafayette St. • Newark 5, N. J.

HERE WE AIM TO BE *Tack-less*

AUTO ARC



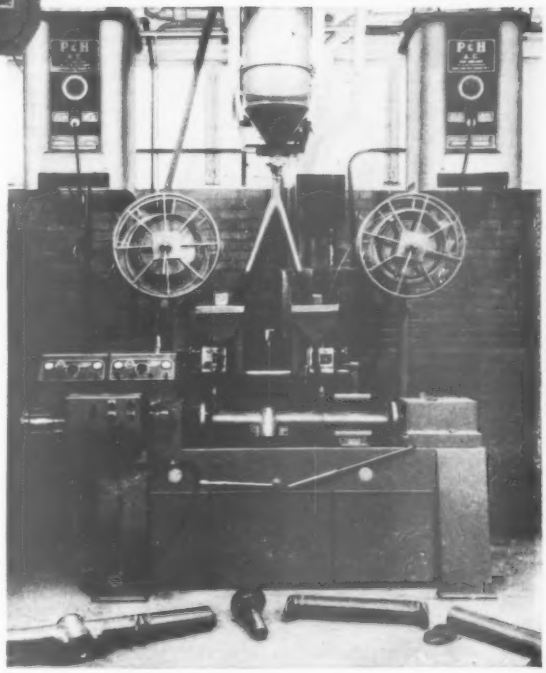
AUTO ARC WELDING HEAD

Component parts of four different weldments are accurately located and machine welded without the usual tack-welding. After locking the parts in position with an air chuck, the operator presses one button to complete all welding operations. To lower production costs—such machines are a must!

The Auto Arc Heads start multiple A.C. arcs simultaneously at low current densities. This starting feature increases the practical range of machine welding.

The lathe type fixture shown chucks the "work" between "face plates" which are geared to rotate as a unit. Weldment parts are kept in positive register by plate adapters. Automatic indexing with adjustable weld overlap obtained by limit switches and mechanical interlocks maintains quality production.

The installation of Auto Arc equipment in the Danuser Machine Company's modern plant illustrates our business. For machine welding with automatic arcs, consult us without obligation.



Auto Arc Equipment used by the Danuser Machine Company of Fulton, Missouri in automatic welding of component parts used in the manufacturing of earth moving equipment and farm tools.

THE AUTO ARC-WELD MFG. CO.

8007 GRAND AVENUE • CLEVELAND 4, OHIO

NEW LITERATURE

Stop Corrosion with Metallizing

Metallizing saves money by giving permanent protection. Ships, tanks, refrigerator cold plates, pole-line hardware, bridges, structural steel—all sorts of iron and steel equipment can be protected for many years by spraying with zinc or aluminum. No further maintenance is necessary for 15 to 20 yr.

All corrosion problems should be considered individually—so that all conditions may be studied. Let metallizing stop corrosion for you. Write for Bulletin 62 or explain your corrosion problem in a letter. Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

New Koven Brochure

A new brochure, Koven's *Men, Facilities and "Know-How,"* has been released by L. O. Koven & Brother, Inc., Jersey City, N. J., metal fabricators of standard and special equipment and apparatus for processing, material handling and storage for all industries.

This attractive, 24-page brochure illustrates by photographs and sketches the complete story of Koven's experience, knowledge and facilities in the field of metal fabrication.

Koven's two large plants are fully equipped for the fabrication of metals in all gages from 18 gage to the heaviest plate. The machine shops, sheet and plate shops and welding departments are all equipped with a complete line of modern equipment of the latest designs. In addition to these departments Koven has a large hot-dip galvanizing shop, metal spraying section, stress-relieving furnace, shot blast rooms, mobile X-ray unit and laboratory and modern spray painting, cleaning and finishing rooms which enable Koven to handle a job, with very few exceptions, completely in a Koven plant.

Copies of this informative brochure may be obtained by writing Koven for Bulletin No. 490.

Welding Chart

The Suffolk Iron Foundry (1920) Ltd., Sifbronze Works, Stowmarket, England, has issued a sliding chart which indicates for each metal to be welded in the various thicknesses, the size and type of rod, type and length of flame, blowpipe size, acetylene consumption, angle of rod and torch and flux, if any.

Lincoln Directory

The Lincoln Electric Co. has issued an attractive directory of 8 pages describing its complete list of welding supplies including various types of electrode holders, protective shields and accessories of all types. The directory includes a list of the various electrodes. Copy may be obtained on request by writing to The Lincoln Electric Co., Cleveland 1, Ohio, for *Bulletin 467*.

Hobart Circular

A new circular has just been issued by the Hobart Brothers Co., Troy, Ohio, describing their new a.-c. welding machines. The circular includes a description of the d.-c. generators as well.

Resistance Welding Pamphlet

The Taylor-Winfield Corporation, Warren, Ohio, has published Bulletin 8-013, describing their Hydro, Ultra, Multi and Air Speed welding machines.

Low Temperature Brazing News

Handy & Harman, 82 Fulton St., New York 7, N. Y., has issued Bulletin No. 47, describing how to make copper tanks through the use of brazing. Detailed instructions are given including, edge preparation, jigging, welding, etc. The circular also includes some applications of silver brazing to farm equipment.

Steel Making

The United States Steel Corp., 71 Broadway, New York 6, N. Y., has issued a new pamphlet, *Steel Making in America*. This pamphlet describes, in simple terms, the manufacture of steel in the United States from raw materials through finished steel products ready for shipment from the mills. A brief history of the iron and steel industry from earliest times to the present is also included.

The book was prepared and published by U. S. Steel primarily for school students in response to thousands of requests received from pupils for information about steel making.

It is hoped that *Steel Making in America* may prove helpful, not only to students, but also to adult laymen, who desire to further their knowledge of the manufacture of the basic metal, steel, which serves them so extensively in their daily lives.

Repair of Gray Iron Castings

Air Reduction has announced the availability of a new reprint, entitled "Repairing Gray Iron Castings by Welding," which originally appeared in *Iron Age*.

The eight-page reprint, illustrated with ten sketches and photographs, offers practical case histories covering the repair and maintenance by welding of cast parts. Specific and factual, the article contrasts three of the most common welding processes—oxyacetylene welding, electric arc welding and carbon arc welding—as applied to a forging hammer anvil base and other cast parts of industrial equipment.

Copies of this latest Air Reduction reprint are available at any Airco sales office or Air Reduction, 60 East 42nd St., New York 17, N. Y.

New Booklet by Fansteel

Nowhere is the importance of modern metallurgy to industry more strikingly attested than in an exceptionally interesting booklet just off the press, issued by Fansteel Metallurgical Corp., North Chicago, Ill.

The booklet bears the title *Fastell (R) for Heavy Duty Electrical Contacts* (Technical Data Bulletin 7.101), but perusal shows that the Fastells have gone beyond the heavy-duty field and are finding more and more applications for light-duty contacts.

In the Fastells, the high melting point, high density, low arc erosion, low vapor pressure, low arcing and nonwelding properties of refractory metals such as tungsten, molybdenum or their carbides are combined with the high electrical conductivity and low contact surface resistance of such metals as silver and copper.

The Fastells are not alloys, they are not bonded. They are, in effect, new metals not to be found in nature—unified through and through by Fansteel metallurgy.

Their service in electrical contacts varies from high-frequency interruption at low current and voltage, to breaker overload protection in currents of several thousand amperes and voltages of several hundred kilovolts. Fastell is efficient where other metals are unable to withstand the action of the electric arc that is drawn between contacts when the circuit is broken.

The booklet goes into much detail on properties and applications. While popularly written it embodies diagrams and data that all design and product engineers will be glad to have in their files.

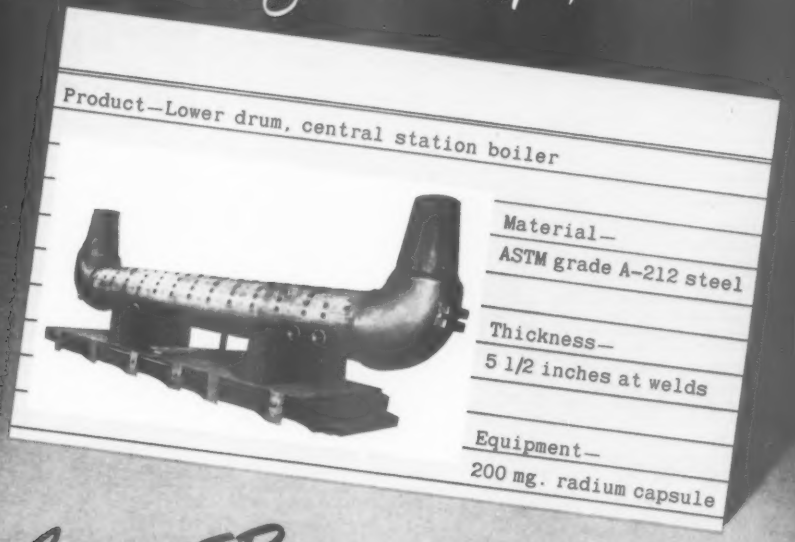
Copies may be had gratis by addressing Fansteel Metallurgical Corp., North Chicago, Ill.

Safety Catalog

A new catalog of protective equipment and safety products has been issued by the American Industrial Safety Equipment Co. of Brooklyn, N. Y., division of The Burdett Oxygen Co., of Cleveland, Ohio.

This 36-page catalog illustrates and describes the many new and improved

What's the *right* X-Ray film?



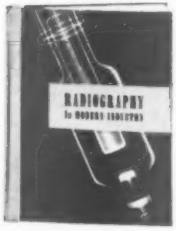
ANSWER:

KODAK INDUSTRIAL X-RAY FILM, TYPE K

● Here was thickness—thickness that demanded the fastest possible film to keep exposure time down. Gamma radiation was to be used.

So the film for the job was Kodak Industrial X-ray Film, Type K, with lead-foil screens.

This is the film that gives you the shortest exposure time for radiography by radium. You use it when checking for significant weld irregularities in thick sections.

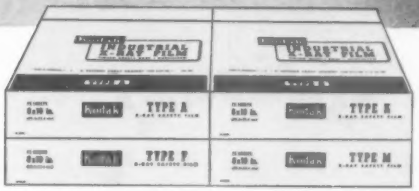


RADIOGRAPHY IN MODERN INDUSTRY

A wealth of invaluable data on radiographic principles, practice, and technics. Profusely illustrated with photographs, colorful drawings, diagrams, and charts. Get your copy from your local x-ray dealer—price $3.

Radiography

...another important function of photography



A TYPE OF FILM FOR EVERY PROBLEM

To provide the recording medium best suited to any combination of radiographic factors, Kodak produces four types of industrial x-ray film. These furnish the means to check welds efficiently and thus extend the use of welding processes.

Type K has medium contrast with high speed. For gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without calcium tungstate screens.

Type M provides maximum radiographic sensitivity, high contrast, and exceptional detail under direct exposure or with lead-foil screens. It has extra fine grain and the speed is adequate for examination of light alloys at average kilovoltage and for much million-volt radiography of steel and heavy alloys.

Type A offers high contrast with about three times the speed of Type M, but with slightly more graininess. Used direct or with lead-foil screens for study of light alloys at low voltages, and of heavy steel parts at 1000 kv.

Type F provides the highest available speed and contrast when exposed with calcium tungstate intensifying screens. Has wide latitude with either x-rays or gamma rays, exposed directly or with lead-foil screens.

EASTMAN KODAK COMPANY
X-ray Division • Rochester 4, N. Y.
"Kodak" is a trade-mark

Kodak

goggles, spectacles, helmets, face shields, lenses, plates and other items in the "Eye-Gard" and "Body-Gard" line.

One of the unusual aspects of this catalog is its arrangement. Each page is made up so that the user can easily identify the application of each product, its construction details and important features and thus select the item to meet his exact requirement.

Free copies of this catalog may be obtained by writing to American Industrial Safety Equipment Co., Dept. C-2, 847 Lexington Ave., Brooklyn 21, N. Y.

Welding Equipment Catalog Available

The Modern Engineering Co., of St. Louis, Mo., manufacturers of MECO welding equipment, has announced the completion of their new catalog No. 140.

Its pages form a comprehensive guide for the welder, covering every type of equipment necessary for all acetylene and oxygen operations.

Containing over 150 illustrations, the text explains each item of equipment in detail and gives specific recommendations for its use.

Your copy will gladly be mailed to you if you write to Modern Engineering Co., Dept. 163, 3415 W. Pine Blvd., St. Louis 3, Mo.

Principles of Magnaflux

The Principles of Magnaflux, 3rd ed., by F. B. Doane and C. E. Betz, published in April 1949 by Photopress, Inc., Chicago, Ill., is bound in a durable cloth cover with illustrated jacket.

The first and second editions of Principles of Magnaflux covered the subject of nondestructive testing with Magnaflux as far as the art had progressed when they were written, but extensive new methods, new materials and new approaches and practices have been developed which render the old editions nearly obsolete.

The third edition of *Principles of Magnaflux* is a rewritten, new book on this valuable and widely used inspection means. The book is organized and written to furnish the supervisory personnel, the inspection heads and the Magnaflux operator with a single ready source of all the information which is needed for the most effective results from his inspection with Magnaflux.

The subject is covered from the basic electrical and magnetic principles which apply, through the range of methods, materials and equipment which are in use, to the newest and most effective high-production equipment.

The complete coverage of the wider aspects of inspection with Magnaflux has resulted in a large-sized, generous book of 388 pages and 170 illustrations. This edition of *Principles of Magnaflux* will serve as a working handbook for those who are regularly using Magnaflux; it will serve as a planning guide to those who are laying out or reorganizing and modernizing complete inspection programs; and it will serve as a valuable reference tool for those whose interest and responsibility covers entire companies and industries, where the best results are to be obtained from entire manufacturing or operating organizations.

Employment Service Bulletin

Position Vacant

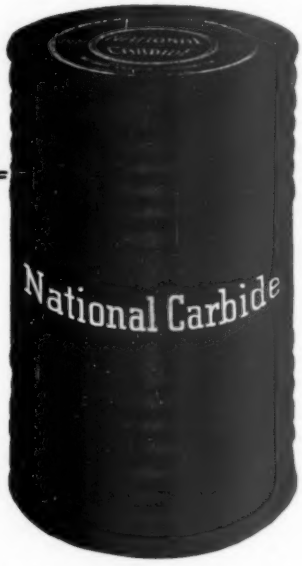
V-237. Chief Welding Instructor. At least 10 years' experience in acetylene and electric arc welding. Thoroughly experienced, practical and theoretical. Must be capable of taking full charge of instructional staff. Salary open. Send detailed résumé of age, education and experience.

Services Available

A-581. Research and Development Engineer desires position. Age 39. B.S. Metallurgical Engineering, Michigan College of Mining and Technology, 1939. Five years' experience in steel mills covering all phases metallurgical control. Experience in fabricating field as Field Metallurgist, Assistant and Chief Metallurgist. Experience in welding including all branches; carbon steels and low and high alloys. Also willing to do sales engineering or production supervision.

National
Carbide
IN THE RED DRUM

EFFICIENT
ECONOMICAL
DEPENDABLE



FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
60 E. 42nd St. NATIONAL CARBIDE CORPORATION New York 17, N. Y.

NEW PRODUCTS

Foundries Producing New Ductile Cast Iron

Ductile cast iron, a new engineering material developed by the International Nickel Co., is now being produced by numerous foundries throughout the United States. The new material combines the process advantages of gray cast iron, such as fluidity, castability and machinability, with the product advantages of cast steel and is characterized by a graphite structure in the form of spheroids. Its excellent mechanical properties, particularly high elastic modulus, high yield strength and ductility, have suggested many potential applications for this ductile cast iron in various industries.

All-Purpose Electrode

A new general-purpose electrode, developed particularly for maintenance and production work on special steels of the high-alloy and high-carbon types, has undergone full-scale field testing and is now being offered from distributor stocks throughout the country, according to an announcement by Bent Laune, president of All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y.

This electrode, identified as All-State No. 252, warrants its being called "general purpose" by its universal versatility. Its tensile strength of 85,000 to 95,000 psi., is accompanied by excellent heat-resistance corrosion-resistance, and wear-resistance. It gives superior performance in welding low-alloy steels without preheat and subsequent heat treat, and in joining dissimilar steels, as well as building up case-hardened parts and welding-clad steels.

The inherent characteristics and the performance indicates No. 252's wide adoption in the chemical and other industries where sulphur gases are a problem, for welding furnace parts for service in temperatures up to 2150° F., and for manufacture and maintenance of mining and railroad equipment, particularly for use in cold climates.

All-State No. 252 is an a.-c., d.-c. electrode. Operators should reverse polarity with d. c. Preheating the base metal to 300–500° F. makes it easy to produce strong, crack-free welds every time. Its yield strength is 50,000–60,000 psi., elongation 35–45 %, reduction of area 35–50 % and impact at room temperature (Charpy Keyhole) 150–175.

Neoprene Hose

Air Reduction, manufacturers of industrial gases and welding equipment, has announced the addition of 3/4- and 1-in. single-line neoprene hose to its stock of welding and cutting accessories.

According to Airco, this addition was made to handle such applications of oxygen as heavy cutting, decarburization of steel and large scrapping operations. It is also anticipated that this large-size hose will find considerable use in oxygen pipe line installations.

Both the 3/4- and the 1-in. diameter hose can be used with oxygen equipment at working pressures of 200 psi. The inner lining of the hose is made of durable neoprene rubber. The remainder is made of vulcanized natural rubber content and tough braided fabric.

Both diameters of the new hose are immediately available in standard 50-ft. lengths. Hose connection fittings and the wrench necessary for assembling are available wherever the hose is sold.

For further information, write the Airco sales office nearest you.

Locating Leaks

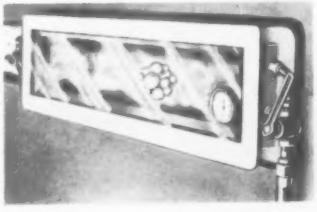
A time-tested but little known device for quickly locating leaks in pipes, tanks or other storage vessels is the patented American Vacuum Seam Tester. The manufacturer, American Pipe & Steel Corp., of Alhambra, Calif., reports that this compact, portable unit effects substantial savings by often eliminating the necessity of taking out of service the old equipment to be tested. In the construction of new tanks and storage vessels, the Vacuum Seam Tester swiftly detects even the smallest unsuspected pin-point leaks, eliminating costly, cumbersome old-fashioned methods.

Tester operates on a simple, efficient vacuum principle. Seams are covered with soapsuds. Inspection box, with clear glass top and soft rubber base, is laid over seam. A powerful vacuum created within the inspection box draws air through any leaks causing soap bubbles to form. These are clearly visible through the glass top. Testers are available in a wide variety of sizes and shapes for inside corners, outside corners, circumferential seams and straight seams.

Tank manufacturers and steel fabricators state that their welders and caulkers work faster and more efficiently because they know that imperfections in their work will be readily detected.

Pipe manufacturers and pipe-line contractors save time and money by using the American Vacuum Seam Tester for preliminary testing of high pressure lines. Pipe line maintenance trucks carry testers as standard equipment.

The American Vacuum Seam Tester is completely guaranteed and immediate delivery is assured by the American Pipe & Steel Corp., 2201 W. Commonwealth Ave., Alhambra, Calif.



Cylinder Carriers

Syracuse Alloy Metals Corp., 116 S. Salina St., Syracuse 2, N. Y., are announcing their new and complete line of SAMCO Cylinder Carriers for Welding Service.

The entire line is of welded construction throughout, and balanced scientifically for safe rolling when loaded. Being streamlined for rapid wheeling in confined passages, they are extremely easy to handle. Tanks are arranged in tandem allowing the truck to store in small space.

Platform plates are electrically welded to the lip of truck and allow for carrying capacity beyond requirements. The truck frame is of heavy wall steel tubing, 11/16 in. O.D., and contoured for nonslip grip. A generous clearance is provided between the truck handle and cylinder regulators. Lock bar is also furnished to hold cylinders in place without shifting.

SAMCO Cylinder Carriers are finished in either aluminum or red enamel. Over-

Here's what they're doing

New technique for welding chrome pipe

Using General Electric welding electrodes the Houston Pipe & Steel Co. has successfully used a new procedure for welding 4-6 chrome pipe *without* the usual time-consuming subsequent annealing procedure.

According to their Chief Engineer, here's how they do it: The joint is first brought up to a 600-800 F temperature using a large preheating tip with oxy-acetylene, and held at that temperature during welding. The welds are then made using G-E Type W-1502 stainless electrodes. Immediately after completing the joint, its temperature is raised to 1200-1350 F, it is wrapped in asbestos tape, and then cooled to room temperature.

Contrary to popular belief, the weld metal *does not become brittle*. Certified laboratory tests indicate very desirable results, including ultimate tensile strength of 73,200 psi, satisfactory 180 degree root bend, Brinnell hardness in the weld of 248 and in the pipe of 174.

"We used this procedure throughout the production of the chrome pipe," states the Chief Engineer, "and the lot was completed satisfactorily, quickly, and inexpensively."

YOU CAN PUT YOUR CONFIDENCE IN . . .

GENERAL ELECTRIC

with G-E Stainless Electrodes

Vertical-down Welding MADE EASIER

● We've made that old bugaboo, the vertical-down weld, say "Uncle!" with a new coating formula on G-E 1000 series stainless electrodes in the $\frac{1}{8}$" and smaller sizes. (The 1000 series have a lime-type coating for reverse-polarity d-c welding; there are 16 standard types for welding various analyses of stainless.) Other analyses may be obtained with the new coating composition upon request.

Already endowed with excellent usability characteristics in the vertical and overhead position as well as the horizontal, their new coating makes them particularly well suited for the ordinarily troublesome vertical-down welding.

G-E stainless steel electrodes are regularly demonstrating their versatility and ability to help solve difficult welding problems. Why not investigate them; your General Electric Arc-welding Distributor carries a complete stock, also including eleven types in the 2000 series with a titania-type coating for use on either a-c or d-c.

FOR OTHER WELDING JOBS there are some 40-odd additional types of G-E electrodes including a most complete line of low-hydrogen types, cast-iron, hard-surfacing, and phosphor-bronze electrodes, as well as mild-steel and general-purpose rod for manual or machine welding. Mail the coupon now for a copy of the handy, pocket-sized G-E electrode catalog.

Stainless steel vertical-down fillet made with new G-E W-1310 electrode; note the smooth, flat appearance. (And if you think appearances may be deceiving, may we suggest the proof of the electrode is in the welding. How about giving them a try!)

HAVE YOU SEEN "ARC WELDING AT WORK"? This 30-minute, sound-color motion picture depicts clearly the design and production advantages inherent in the three basic types of arc welding. Ask your G-E Arc-welding Distributor. Mail the coupon to him, or to:

Dept. E712-1, Apparatus Department
General Electric Co., Schenectady 5, N.Y.

Send me bulletin GES-3571, pocket-sized electrode catalog.

Name .....

Company .....

Address .....

City ..... State .....

ARC WELDERS · ELECTRODES
ACCESSORIES · RENEWAL PARTS

all height 40 in., length 20 in., width 13¾ in.

SAMCO Cylinder Carriers are equipped with either 8- x 1-in. clincher-type solid rubber tires or 10- x 1.75-in. semipneumatic rubber tires, mounted on heavy gage, double steel disk, spot-welded wheels and ½-in. ball bearings. Each of the three models are shipped assembled, and delivery is immediate.

Lightweight Spot Welder

Larkin Lectro Products Corp., 160 W. 146th St., New York, N. Y., has developed a new, lightweight line of spot welders, ranging in size from 5 to 30 kva. This line of welders is characterized by an entirely different principle of construction, with the upper horn contained in the secondary of the transformer and the secondary coming right up to the top of the welder acting as head of the unit. This streamlining of construction provides greater efficiency and compactness over all. Where high-speed production is required, without investing in expensive timing equipment, the Larkin Royal Welder furnishes speed through its unique switch. This switch is manufactured with extra-heavy contacts which have longer than average life. Yet, it is ideal for continuous, speedy production of innumerable items such as wire goods, small parts, lamp frames, etc.

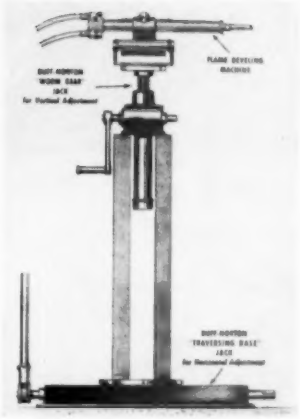
Worm Gear Jacks Solve Flame Beveling Problem

A long-standing problem of flame beveling tank sheets preparatory to welding was solved recently by a unique application of Duff-Norton versatile worm gear jacks and traversing bases.

Preparatory to welding, tank sheet edges had been beveled by means of a flame-beveling machine. For some time this machine was mounted on a stationary frame, and the tank was raised or lowered to accommodate the height of the frame. This was not only a laborious and costly operation, but also had to be executed with extreme care for consistently good results.

In studying the operation, Duff-Norton engineers realized that a more desirable method would be to make the beveling machine frame vertically mobile. It was found that by mounting the flame bevel machine on a frame controlled by three vertically positioned worm gear jacks that the bevel machine could be quickly raised or lowered to the desired level. This operation is not only far easier, but is also much more exact. Three Duff-Norton traversing base jacks were mounted at the bottom of the frame to permit horizontal movement. Also, additional vertical adjustment is made possible by the use of two traversing bases at either end of the tank.

This problem of flame beveling tank sheets is one of the many problems which have been solved through the use of worm



gear jacks and traversing bases. Duff-Norton engineers are available for consultation without obligation on any lifting, lowering or horizontal moving problem.

Duff-Norton worm gear jacks may be used in horizontal, inverted or vertical positions. Jack capacities range from 5 to 50 tons with raises from 3 to 25 in. Traversing base jacks have capacities from 25 to 75 tons, and raises from 9 to 12 in. Additional information on these highly adaptable jacks may be obtained direct from the Duff-Norton Mfg. Co., 2709 Preble Ave., Pittsburgh 30, Pa.

WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

J. H. Williams & Company
Buffalo 7, New York

G. D. Peters Company
Montreal 2, Canada
Canadian Representative

SPECIALIZING IN "BETTER-BUILT"
WELDING & SAFETY EQUIPMENT
FOR OVER 25 YEARS

There is a DOCKSON distributor near you. Name on request.

Write for our complete Welding and Safety catalogs.

Dockson CORPORATION
3839 WABASH • DETROIT 8, MICH.

All through the summer—through hot, humid days and hot, humid nights—the biggest thief in America will be raiding your plant. Wherever steel is handled—where it is stamped and milled or machined or ground, where it is pickled or cleaned or assembled—RUST will be busy, robbing you of production, robbing you of profit.

But you don't have to put up with this moist-month thievery. The Oakite Technical Service Representative in your vicinity is well equipped with materials and methods for fighting RUST. Phone him today for expert help in arresting RUST in every part of your plant.

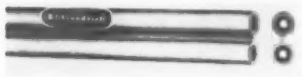
FREE There is no charge for Oakite advisory service on any problem of metal cleaning. Write to Oakite Products, Inc., 18E Thames St., New York.

OAKITE
INDUSTRIAL CLEANING MATERIALS • METHODS • SERVICE

Technical Service Representatives Located in Principal Cities of United States and Canada

Hose

A twin oxyacetylene hose in which two lengths, one red and the other green, are joined by a thin strip of rubber is announced by The B. F. Goodrich Co., Akron, Ohio. The hose will be marketed under the brand name Duo-Weld.



The new product employs the same high-quality compounds utilized in the company's standard single oxyacetylene hose. Molded finish cover is smooth, tube exceptionally smooth and uniform. Reinforcement consists of one braid of high-tensile hawser cord cotton yarn which in the $^1/_4$-in. size gives strength comparable to the standard two braid single-line construction.

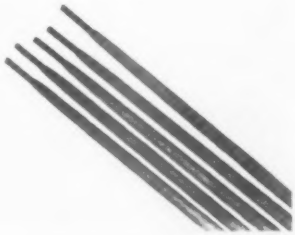
The rubber strip joining the two hose lengths is of high-quality rubber stock with extreme flexibility. The strip also allows the hose to be separated into single lengths, when that is desirable, without tearing into the cover of either length.

The hose is being made in 50-, 25- and 12$^1/_2$-ft. lengths, with the $^1/_4$-in. size being stocked. Each length is separated approximately 18 in. from each end and secured with a metal ferrule at the separation point.

Hard-Facing Electrode

A new hard-facing electrode for extreme abrasion and mild impact that is encountered in mining, cement, dredging, excavating, construction and power industries. This hard-facing rod is extremely easy to apply on carbon or manganese steel parts. It is available in 14-in. lengths, diameters of $^1/_8$, $^3/_{16}$ and $^1/_4$ in. The Rockwell C hardness of this rod is 61 to 65, as deposited. It will not anneal under heat, a true stable hard-facing rod.

A few recommended applications are clam shell bucket lips, waste heat fan blades, conveyor screws, pug mill shoes, dry pan scraper blades, drag-links, cement tube liner plates, coke pusher shoes, coke oven scrapers, dredging cutters, dredging pump impellers and concrete mixer arms. Wall Colmonoy Corp., 19345 John R. Street, Detroit 3, Michigan.



Chippers' Goggles

A new chipper's goggle, compression-molded of an extremely strong and durable phenolic compound and featuring dome metal side screens, is announced by American Optical Co.

The domed side screens provide a greater cup area for cooler, safe ventilation and more side vision, while the phenolic frame is nonflammable, moisture and heat-resistant—assures better facial fit and maximum protection plus wearing ease. The individually molded, nonreflecting eyecups have larger, rounded, face-contacting edges and will withstand considerably more impact than conventional goggles.

Other features of this new chipper's goggle include a chain bridge enclosed in a form-fit plastic-covered tube which rests lightly on the nose, large lens rings, one-piece rubber headband and improved

The CHAMPION of all general purpose electrodes

IS THE

GRAY DEVIL #2

D. C. Straight Polarity (May be used with A. C.)

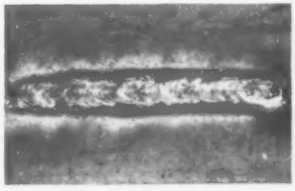
AWS CLASS E 6012

Welding supervisors have long sought an all-purpose electrode which would withstand high currents without loss of efficiency—THAT'S GRAY DEVIL #2!

Operators have always wanted a straight polarity rod which could be used with plenty of heat without the usual penalty of excessive globular spatter—THAT'S GRAY DEVIL #2!

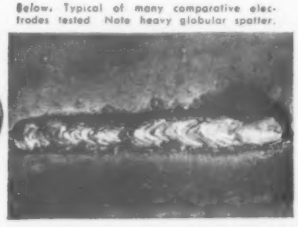
Welding engineers have required a general purpose, poor fit-up electrode which would consistently produce good quality welds of uniformly smooth appearance, excellent slag characteristics and ease of handling in all positions—THAT'S GRAY DEVIL #2!

Send for free samples—try them and be convinced



Above: CHAMPION Gray Devil #2. Note absence of spatter at high amperage.

Below: Typical of many comparative electrodes tested. Note heavy globular spatter.



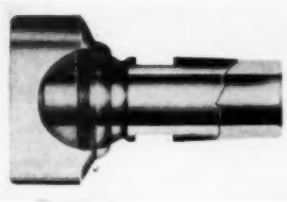
THE CHAMPION RIVET COMPANY

CLEVELAND, OHIO EAST CHICAGO, IND.

over-all style and appearance. The goggle is fitted with regular Super Armorplate plano lenses, but can be had with six curve-clear or Calobar types if desired.

Swivel Resistance-Welding Electrodes

Substantial improvement in performance of swivel-type, resistance-welding electrodes has been accomplished by P. R. Mallory & Co., Inc., Indianapolis, Ind.



In the new design, the water hole is drilled completely through the shank, bringing cooling water directly in contact with the swivel head. Tests indicate a stabilized operating temperature of 94° C. for the new unit, compared with 332° C. for the earlier design. This reduction materially increases the life of the swivel tip and enable it to produce more sound welds of a higher strength.

The new electrode is now in production.

Wire-Packaging Aluminum Spools

Strong, light-weight, aluminum spools for packaging wire and textile fibers are now being Heliarc welded by Acrometal Products, Inc., of Minneapolis, Minn. The Heliarc process is an inert-gas-shielded electric arc-welding method for welding without flux. The arc is struck between a tungsten electrode and the work piece. Argon is directed through the head of the torch to blanket the electrode and weld puddle, thus shutting out the air and preventing oxidation.

Fig. 1 Mechanized setup for Heliarc welding aluminum spools for packaging wire and textile fibers

A mechanized setup is shown in Fig. 1. This setup employs two Heliarc torches to make simultaneous circumferential welds on each spool. Flanged end pieces are joined to a center section of tubing. The welds are so smooth that usually no post-weld treatment is required. Since no flux is used, there is no spatter or corrosive flux residue to be removed.

The welding operations are semiautomatic. An air cylinder holds the end-pieces and center tube in position for welding. After loading the jig, the operator pushes the control button to start the welding cycle. The jig turns the spool at a constant speed, and the welding current is shut off automatically when the welds are completed. Argon continues to flow for a few seconds after the arc is stopped, in order to allow the tungsten electrodes to cool without oxidizing, then the gas is shut off completely.

Component parts of the spools are mounted in the jig, welded and dismounted in about 40 sec.—actual welding time is 32 to 35 sec. Two 300-amp., a.-c. transformers, with built-in high frequency, supply the welding current at approximately 160 amp. The tungsten electrodes used in the Heliarc torches are $\frac{1}{8}$ in. in diameter and the argon flow is 8 liters per minute.

Material used in the fabrication of these spools is type 52 S0 aluminum, 0.903 in. thick. Formerly, the spools were made of wood or metal parts and were joined mechanically. Since the fabricator has started using the Heliarc process to make the spools of aluminum, they have proved to be vastly superior by being both lighter and stronger than the former products.

Scarfing Torch for Steel Industry

Air Reduction, manufacturers of industrial gases and welding equipment, has announced the availability of a new oxy-acetylene scarfing torch for steel mill work. The new torch, complete with starting rod device, is the result of extensive field and laboratory research. According to the manufacturer, the torch offers the following advantages:

High Gas Capacity—5000 cfh. at 100 psi. This extremely high flow-rate permits maximum output per man-hour.

Light Weight—The torch, including starting rod attachment, weighs just 6 lb.,

Buy "PROVEN FLUXES"

Years of GUARANTEED SATISFACTION

behind these GOOD

"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Alumimum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By

ANTI-BORAX COMPOUND CO., INC.

Fort Wayne, Ind.

NET MONTHLY ADVERTISING RATES

Black and White — **Effective July 11, 1947**

Space	One Insertion	Three Insertions	Six Insertions	Twelve Insertions
*Full page	$185	$165	$150	$140
Two-thirds page	130	120	110	100
Half Page	105	95	85	80
Quarter Page	60	58	55	50
Eighth Page	40	35	30	28
*Inside Preferred	205	185	170	160

10% Extra for bleed full pages. Color $65 extra per color added

Agency Commission —15%

Cash Discount — 2%, 10 days

a new edition

of

Welding Metallurgy

First published in 1940, this book has had several printings and has been distributed all over the world. To bring up to date, Mr. G. E. Linnert has prepared an extensive revision so that the new edition has 505 pages—150 pages more than the first edition. Many new illustrations have been added so bring the total to 203.

Material has been added to cover the new processes such as inert gas metal-arc welding; material has been added to provide greater coverage of the stainless steels.

A list of books is given at the end of each chapter for those especially interested in the subject covered by that chapter. Questions for school use are grouped together at the end of the book; they can be used for home study as well.

$2.50 per copy. Order through American Welding Society, 33 West 39 Street, New York 18, N. Y.

Ampco* **Makes Seam-Welder Shafts Last Longer on High-Pressure Jobs**

— reduces welding and forming costs on aluminum, stainless steel, tubing, etc.

Outer Sleeve — Ampcoloy 97 or 95
Roller or Sleeve Bearings — Ampcoloy 86
Inner Sleeve — Ampcoloy 97 or 95
Shaft — Ampcoloy 95 or 97
An AMPCO alloy
An AMPCO alloy
An AMPCO alloy
An AMPCO alloy

AMPCO triples shaft life . . .
CUTS resistance-welding COSTS

Proved by savings in maintenance and downtime — in Indiana Plant

Ampco Metal sleeves and bearings give this shaft the guts to take the heavy punishment of forming and welding in one high-pressure operation. Analyze your own jobs — see how durable Ampco products can make similar savings for you!

This combination of toughness and hardness in Ampcoweld tips and wheels resists mushrooming and wear. Their high electrical conductivity resists sticking to work. They require less dressing. That's why you can count on minimum downtime, top production — greater profits. All Ampco resistance-welding products meet R.W.M.A. specifications.

AMPCO®

Ampco Metal, Inc.
Milwaukee 4, Wis.

West of the Rockies it's the Ampco Burbank Plant, Burbank, California

Send for detailed information on Ampco Resistance Welding

Tear out this coupon and mail today!

Ampco Metal, Inc., Dept. WJ-8, Milwaukee 4, Wis.
Please send me Bulletin 68B.

Name..... Position.....
Company.....
Company Address.....
City..... (.....) State.....
M-13

*Reg. U. S. Pat. Off.

considerably lighter than any comparable torch now available. The light weight was achieved without sacrificing ruggedness, by making use of aluminum parts wherever possible and by the elimination of excess metal.

Sturdy Construction—The new Airco scarfing torch is constructed of stainless steel, Monel and aluminum. The torch head is made of Type 304 stainless steel, as are the tubes. Wear ribs, located on both sides of the torch head, are an added feature that will materially increase the work-life of the torch.

The Airco mild steel scarfing torch is a two-hose type with triangular tube arrangement and is available in 46- or 52-in. lengths and features a starting rod attachment of an entirely new design. The operating mechanism for the attachment is an integral part of the torch. A dual internal lever system makes possible an independent starting of this device, prior to the application of scarfing oxygen.

Simultaneously with the announcement of their new scarfing torch, Air Reduction also disclosed that two new style scarfing tips are available for use with this torch. The first tip, Style 211, is an acetylene scarfing tip. It has flared oxygen orifices in order to obtain a wider kerf. This tip is available in sizes 17 and 18. The same tip, available for use with natural gas, will be known as the Style 117. This also is available in sizes 17 and 18.

For further information about the new Airco scarfing torch, write the Airco sales office nearest you, or Air Reduction, 60 E. 42nd St., New York 17, N. Y.

Pipe End Forming Machine

Only 10 sec. are required to close completely the end of a 4-in. diameter tube with $^1/_4$-in. wall thickness when using the latest Westin Process Forming Machine recently manufactured and shipped by The Federal Machine and Welder Co., Warren, Ohio, designers and builders of resistance-welding equipment.

With the use of removable dies, this general-purpose machine is suitable for a variety of job applications. (Single-purpose machines, especially desirable for continued high production of a single item, are also available.)

Once the machine has been initiated by a push button at the operating station, the forming cycle is fully automatic. For short runs of special work, manual operation is provided, controlled by means of a selector switch, with separate push buttons for control of the clutch, chuck and current initiation. A hand lever, in this case, controls the platen traverse.

The traverse speeds are infinitely variable from 0 to 100 in. per minute, and the 8-step spindle speed ranges from 40 to 150 rpm. The three-segment die and three transformers permit equal loading of each phase of the conventional three-phase system, thus providing economical operation due to the lighter electrical demand.

Accurate control of forming temperatures provides even heating which prevents work hardening or formation of strain flaws, thus eliminating annealing and postheating normally required by other methods.

The quality of the product formed is also accurately controlled, producing scale-free, smooth surfaces, no porosity, no twisting of the tubing during forming and the metallic structure of the work is kept within controlled limits.

Although generally built in nominal sizes to accommodate work ranging in diameter from $^3/_4$ to 4 in., 4 to 8 in. and 8 to 16 in., machines can be built for working tubing of almost any diameter or wall thickness.

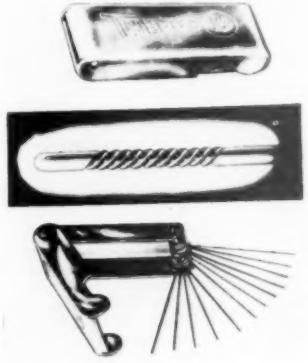
Brass, aluminum, copper, carbon steels and most alloy steels, including stainless, are being successfully worked by the Westin Process, and experiments indicate that other metals also will lend themselves to this newest of metal-working techniques.

New Cylinder

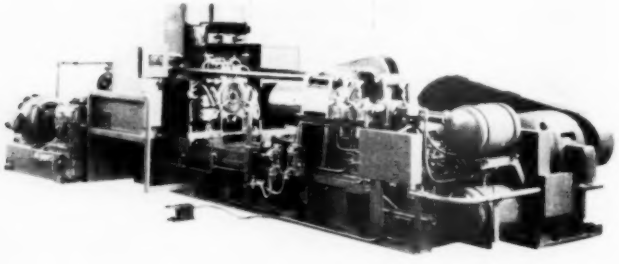
Compressed Gas Cylinders, Inc., 2309 E. 54th St., Vernon, Calif., announce the manufacture of a new, sturdy, lightweight 5-gal. propane capacity cylinder designed and engineered for trailer and small homes or industrial use. These new cylinders are of two-piece, cold-drawn steel construction and have a tare weight of 22 lb. The single center circumferential weld is X-ray controlled for extra safety. They have a full-size 10% outage gage that does not stick. All cylinders are tested to ICC 4B 240 Specifications and are uniformly marked. They are available with a removable cap or permanent guard.

Tip Cleaner

Above is shown the new Spiral Thermo Welding Tip Cleaner with cleaning ridges that allow carbon and slag to be cleaned out of the tip without jamming and scratching the orifice.



Note enlarged view of cleaning ridges showing spiral form and rounded ridges. This spiral design eliminates horizontal cleaning ridges that form breakage points. For this reason Spiral Thermo Tip Cleaners are guaranteed against breakage. Broken cleaners will be replaced free of charge by dealers or by any Thermacote Co. branch in Chicago, Newark, Portland and Los Angeles.



Welder's Goggle

A new welder's goggle, compression-molded of an extremely strong and durable phenolic compound that is nonflammable, moisture- and heat-resistant, is announced by American Optical Co.

The new goggle features an indirect-ventilated, louver side shield and individually molded, nonreflecting eyecups which provide a snug, pleasant fit. The eyecups have larger, rounded, face-contacting edges and will withstand considerably more impact than conventional goggles.

Other features include wide-angle vision, a chain bridge enclosed in a form-fit plastic-covered tube which rests lightly on the nose, large lens rings, one-piece rubber headband and improved over-all style and appearance. The goggle is fitted with 50-mm. round Noviweld lenses in shades 3, 4, 5, 6 or 8; and also Noviweld Didymium lenses in shades 3 4, 5 or 6.

Small Arc Welder for Light-Gage Welding

A small, low-cost arc welder, operating off a 110-v. light circuit, yet having design and operating characteristics comparable to larger industrial welders, is for the first time available for repairing and fabricating in light-gage metals. The Lincoln Electric Co. of Cleveland, Ohio, world's leading manufacturer of welding equipment, is announcing the production of the "Linewelder 60" for use in body repair shops, bicycle, radio, refrigerator repair shops, motor repair shops and for use by plumbers, millrights, heating, electrical and sheet metal contractors. It is also an ideal basement workshop tool for making home repairs to cars, metal furniture, broken castings and pipe, as well as for building different kinds of shop and home equipment.

With a maximum output of 60 amp., the "Linewelder 60" can be used for a variety of light-gage, metal-working jobs, as well as for joining heavier material such as strap, pipe tubing, angle and other shapes. The unit may also be used for cutting metals, soldering and making wire connections, brazing, heating for bending and, with a small rectifier, for battery charging. For repairs and fabricating in sheet metal it offers a method of welding, soldering and brazing that is faster, easier and better than conventional methods. Arc welding reduces distortion difficulties in welding metal as thin as 20 gage and reduces the cost of such work to a fraction of the cost with other methods.

"Linewelder 60" and accessories for welding, soldering and brazing light-gage metals

The "Linewelder 60" is industrially designed and made with electrical steel, mica insulation and glass-covered copper windings. It is approved by Underwriter's Laboratories and is simple and safe to use. It operates off the standard 110-v. light circuit fused for 30 amp., and weighs approximately 50 lb. It can easily be carried by its handle, plugged into the nearest light socket and used wherever it is needed. Simplified controls make it easy to learn to operate the unit and result in an ideal tool for repair or fabricating work.

The "Linewelder 60" is available through Lincoln dealers and is sold complete with 6-ft. insulated cord and standard plug for conventional 110-v. light socket, protective welding head shield and lens, electrode holder and 9-ft. cable, ground cable, a supply of electrode and brazing rod. Price complete is $45.

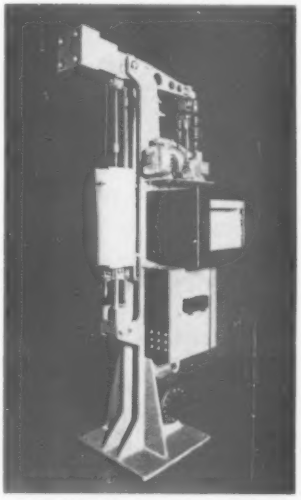
Relaxation Machine

Relaxation tests at temperatures up to 1800°F. can be carried out automatically, including a record of the rate of decline of load, by means of a new machine of 4000 lb. capacity announced by The Baldwin Locomotive Works, Philadelphia 42, Pa.

Relaxation occurs when a material is stretched to, and held at a given elongation, as in bolts, particularly at elevated temperatures. Creep then tends to elongate the bar and release the load. Elastic shortening balances this effect and total strain remains constant. Plastic elongation can be measured by the decrease in stress.

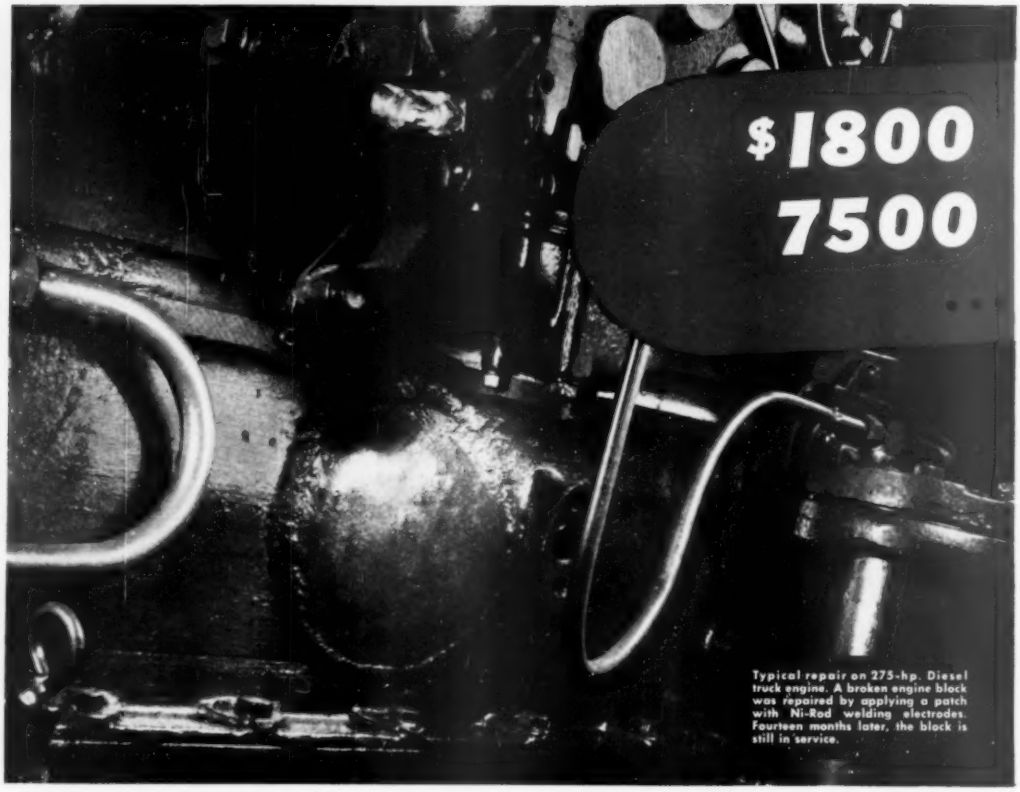
Relaxation tests are also useful beyond the direct application of data on the behavior of metals at constant total strains. They establish the relative ability of a material to withstand stress at high temperature. They are also valuable in estimating creep values in certain ranges of stress and temperature for high-strength alloys and in predicting mechanical properties of metals at high temperatures. Tests of 150-hr. duration have been commonly employed.

The machine automatically relaxes tensional loads from as high as 40,000 psi., permitting strain increments of only 2 x 10^{-6} in. per inch of the 6-in. gage length of a standard 0.356-in. diameter specimen. These increases in length are detected by a highly sensitive extensometer with electric contacts that close a 6-v. relay and



thus operate a 1/6-hp. servo motor to reduce the load enough to open the contacts again and to maintain a substantially constant strain.

The machine has a welded steel frame, is 7 ft. high and occupies a floor area of 25 x 30 in.



Typical repair on 275-hp. Diesel truck engine. A broken engine block was repaired by applying a patch with Ni-Rod welding electrodes. Fourteen months later, the block is still in service.

IN the open-pit nickel mines at Copper Cliff, Ontario, Diesel trucks haul 32-ton ore loads up steep, winding roadways. After several thousand hours of this severe service, failures develop in castings and engine parts.

A serious type of failure is the cracking of cast iron cylinder blocks. New engine blocks cost $644.09 each ... a price that makes the prospect of repairs very attractive.

In the past, damaged blocks have been repaired by oxy-acetylene welding, a relatively critical and time-consuming process. But recently, repairs have been made with metal-arc welds, using Ni-Rod* electrodes. This technique has been completely successful, and the use of Ni-Rod electrodes has given excellent weld quality and has cut welding time.

Here are three typical case reports on repairs made with Ni-Rod:

"1. Block broke in crank chamber after 9381 hours of service. A patch was welded in with Ni-Rod. Since the repair, the block has operated 2064 hours and is still in good condition. Cost of welding was $12.75.

"2. Crank shaft failed after 1746 hours. The broken end engaged the main bearing shells, turning them in the block, heavily scoring the saddle. Repairs were made by machining the bearing area to .100-inch oversize, building up with Ni-Rod, and finally machining to correct size. This prolonged the engine life by 4087 hours. Cost of the entire repair was $40.60.

"3. Crank shaft failed after 4540 hours, causing damage similar to that described in Case 2, above, and was repaired the same way. The engine is still in operation 1369 hours after the repair. The cost of repair was $42.50."

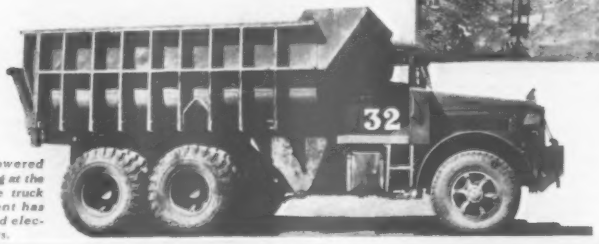
SAVED . . .
HOURS MORE SERVICE
from truck engines repaired with NI-ROD

The three blocks described have a total replacement value of $1,932.27. Subtracting the repair costs, there is a net saving of $1,836.42, and a gain of more than 7520 hours of operating service.

Maintenance stories such as these...three of hundreds in our files... show why 4 out of 5 shops re-order Ni-Rod, once they've tried it. If you are not yet familiar with Ni-Rod's outstanding advantages, why not order a package today? Your nearest INCO distributor stocks Ni-Rod in 3/32", 1/8", 5/32", and 3/16" diameters.

Send for your free copy of: *"NI-ROD—A New Electrode for Any Cast Iron Welding."*

The Frood Stobie Mine, Copper Cliff, Ontario, operated by The International Nickel Company of Canada, Ltd.



One of the Diesel-powered trucks used for ore hauling at the Frood Stobie Mine. The truck maintenance department has standardized on Ni-Rod electrodes for cast iron repairs.

HERE'S WHAT NI-ROD GIVES YOU

in performance

- Stable arc in all positions
- Smooth bead contour
- Excellent wash
- Easy slag removal
- Preheating seldom required
- Works on both AC and DC

in weld quality

- High-strength deposit
- Easy machinability
- Thorough fusion
- Freedom from cracks and porosity
- Close color match

in usefulness

- General repair and maintenance of cast iron parts, including build-up of worn surfaces
- Quick remedy for minor flaws in new castings
- Correction of machining errors
- Assembling cast iron to steel

EMBLEM OF SERVICE INCO NI-ROD TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street, New York 5, N. Y.

*Reg. U. S. Pat. Off.

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,470,763—Flux Coated Aluminum Rod for Gas Welding—Dorris Monnell Doyle, Springfield, Pa.

This patent covers a flux particularly adapted for use in welding aluminum. The flux has 40% of lithium chloride, about 40% of sodium fluoride and about 20% of calcium fluoride in it.

2,471,029—Portable Welder—Ewell W. Forkner, Cincinnati, Ohio.

The welder of this patent is provided with a substantially C-shaped yoke and one electrode is fixedly secured to one end of such yoke. At the other end of the yoke, a cylinder is provided with a movable piston therein. This piston positions an electrode on the end thereof adjacent to the electrode bearing end of the yoke and such electrode is movably supported for applying pressure to a workpiece positioned between the two electrodes carried by the yoke of the welder.

2,471,340—Electrode Holder—Robert F. Morrissey, South Britain, Conn.

Morrissey's holder includes a hollow elongate body that positions an electrode tip at one end thereof. Special tubular means are provided in the bore of the elongate body and are adapted to be moved axially of the body to eject an electrode tip therefrom. The electrode holder may have water present therein and the ejecter means for the electrode tip are adapted to seal such end of the electrode holder after the tip is ejected therefrom.

2,471,478—Flexible Electrode for Welding—Karl K. Breuckner, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

This novel electrode comprises a flexible electrically conductive member which has hydraulic means associated therewith for forcing the member into intimate contact with the article to be welded. Uniform heating of the article by electric current carried thereto by the flexible member is provided to accomplish uniform welding of the article.

2,471,719—Automatic Welder's Hood Control—Wilgus S. Broffit, Indianapolis, Ind., and Homer F. Montague, Lexington, Ky.

The hood control of this patent relates a helmet which has an opening therein protectable by a shield movable into and out of registration with the opening. Movement in one direction of the shield is electrically controlled. Electric coupling and circuit control means are connected to the shield so that the shield must be in register with the opening, and the electrode in contact with the work before welding conditions can be effected.

2,471,881—Portable Welding Device—Matthew J. Manning and Paul F. Elsen, Detroit, Mich., assignors to The Budd Co., Philadelphia, Pa., a corporation of Pennsylvania.

The portable welding device disclosed includes a transformer having a secondary with a base portion and a loop extending transversely therefrom on one side. A welding unit is mounted on the secondary base portion on the side opposite to said loop.

2,471,931—Welding Electrode for Hard Facing—Rene Castro, Ugine, and Andre Lebet, Albertville, France, assignors to Societe d'Electro-Chimie, d'Electro-Metallurgie et des Acieries Electriques d'Ugine, Paris, France, a corporation of France.

The electrode is made from an intimate mixture of an oxidized compound of a metal selected from the group consisting of tungsten and molybdenum, and an iron alloy adapted to form a metallic binding medium for the carbide of the selected metal. A proportion of carbon is present in quantity large enough to reduce the oxidized compound and to form a carbide with the reduced metal, and a binder is also present. This binder is adapted to form no residuum when heated to the melting temperature of the metallic binding medium.

2,472,095—Resistance Welding System—John W. Dawson, Auburndale, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

Dawson's welding system includes a combination of an inductance, and a load circuit operatively related thereto. Means are provided for supplying a magnetomotive force to the inductance and other means are present for supplying an auxiliary magnetomotive force to the inductance to maintain the flux therein and for simultaneously cutting off the first-named magnetomotive force. Yet other means are provided for causing the auxiliary magnetomotive force to decrease to cause collapse of the flux and delivery of the energy thereof to the load.

2,472,110—Condenser Welding System—Hans Kiemperer, Belmont, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

In this welding system a plurality of condensers are provided and means are present for charging the condensers. The welding load circuit is connected to the condensers so that as one condenser is discharged into the load circuit, means are present in the circuit and become active upon substantial discharge of one condenser to discharge another of the condensers into the load circuit.

2,472,171—Method for Producing Electrodes for Electric Arcs—Marcel Victor Oswald, Paris, France, assignor to Societe Le Carbone Lorraine, Paris, France.

Oswald's electrode producing method includes the steps of forming a paste from a solid carbonaceous material, an organic silicon compound and an organic volatile solvent. The paste so obtained is then shaped and afterward subjected to a hardening treatment.

2,472,173—Welding Electrode—Raymond E. Powell, Westfield, N. J., assignor to Western Electric Co., Inc., N. Y., a corporation of New York.

The patented electrode includes a body of conductive material having a groove substantially circular in cross section extending at an angle relative to the center line of the body through one end of the body. A circular tip member is disposed in the groove and extends beyond the adjacent ends of the body.

2,472,177—WeldingElectrodeHolder—Clifford W. Taber, Pasadena, Calif.

Taber's holder includes a pair of opposed jaw carrying members that are hingedly connected together. A compression spring is provided between the members for urging the members to cause their jaws to clamp upon an electrode positioned therebetween. Insulating means are present in the holder.

2,472,205—Rheostat for Welding—Paul S. Greider, Aberdeen, Md.

This patent discloses a special type of a rheostat for use in a welding system.

2,472,323—Arc Welding—Alanson U. Welch, Jr., Pittsfield, Mass. Assignor to General Electric Co., a corporation of New York.

This arc welding method includes providing an arc energized from a source of alternating current with the arc passing between electrodes that have substantially different electron emissivities at the temperatures produced by the operation of the arc. This difference in electron emissivities acts to produce a substantial direct current component of current flow through the arc and this direct current component is reduced to zero by reducing the conductivity of the energizing circuit of the arc during half cycles of that polarity of the alternating current source when the arc is more conductive, as a result of the difference in electron emissivity of the electrodes.

2,472,368—Plasticity Responsive Welder—Irvin W. Cox, West Allis, and Lester D. Drugmand, Greenfield, Wis., assignors to Cutler-Hammer, Inc., Milwaukee, Wis., a corporation of Delaware.

This welding system has relatively movable electrodes that have a pressure supply secured thereto. Control means subject to control by the pressure to which the electrodes are subjected are provided as are control means subject to actuation by relative movement between the electrodes. Additional means are under the control of the said two control means and are responsive jointly thereto for the supply of welding energy to the electrodes. The control means subject to actuation by relative movement of the electrodes are so constructed as to initiate welding in any of a multiplicity of relations of the electrodes and to thereafter initiate termination of welding as the relationship of the electrodes changes with plastic deformation of the material being welded.

2,472,803—Welding Apparatus—Frederick C. Beyer, Washington, D. C. and Clarence E. Jackson, Niagara Falls, N. Y.

The welding apparatus of this patent includes a bed having a carriage supported on and movable therealong. A welding head is mounted on the carriage and adapted to move thereon in a horizontal plane. Means are provided for controlling the movement of the welding head to cause the welding head to reciprocate across the line of advance of the carriage and further means are associated therewith for imparting a component of motion parallel to the direction of movement of the carriage to the welding head. Thus a substantially semielliptical movement is imparted to the welding head.

2,472,848—Method of Electric Butt-Welding Metallic Container Seams

2,472,849—Apparatus for Electrically Welding Container Seams—Horace J. Paynter, Union, N. J., assignor to American Can Co., New York, a corporation of New Jersey.

These patents issued to Mr. Paynter relate to a special method and apparatus for the welding of tubular material such as can seams.

2,472,851—Apparatus for Electromagnetically Controlling Welding Arcs—George G. Landis, South Euclid and Norman J. Hoenie, Cleveland Heights, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

In this patent, an annular electrode is provided and it is transversely split to permit relative movement of its parts. It is adapted to be supported with one face in spaced relation to a workpiece and a conductor of electric current is connected to one end of the electrode and formed into a plurality of insulated turns concentric with the axis of the latter. A second conductor is provided and connected to the workpiece so that upon connecting the conductors to a suitable source of current an arc will be formed between the electrode face and the workpiece and a magnetic field induced by flow of current through the turns of the first conductor will cause the arc to travel in a circular path defined by the electrode face.

2,472,923—Method for Striking the Welding Arc in Automatic Electric Arc Welding Machines—Raoul Jean Schmerber, Uccle, Belgium, assignor to La Soudure Electrique Autogene, Societe Anonyme, Brussels, Belgium.

This patented method consists in short-circuiting the metal end of the electrode and the part to be welded and of providing a fuse on the end of the electrode. This fuse is made from an iron body and at least a chromic acid compound forming, with the iron of the body, a compound having high heat formation and thereby producing an initial ionization of the space between the metal of the electrode and the part to be welded.

2,472,948—Cutting and Welding Machine—Harry A. Huff, Jr., Jersey City, N. J., assignor to Air Reduction Co., Inc.

The cutting or welding machine of this patent includes a self-driven wheeled carriage that positions a torch arm mounting member thereon in a specially controlled manner.

2,472,951—Method and Apparatus for Controlling Torch Spacing—Henry O. Klinke, Forest Hills, N. Y., assignor to Air Reduction Co. Inc., a corporation of New York.

This patent relates to gas torches wherein the flame shows a light area when the cone is out of contact with the work and shows a dark spot at the center of the light area when the cone touches the work, and which increases in size as the distance between the torch tip and work becomes less. The method includes photoelectrically converting into electric current variations in the amount of light at the area where the flame cone impinges on the work resulting from the change in the size of the dark spot thereof when the spacing of the tip from the work surface changes from a desired normal. The spacing of the torch tip from the work surface is automatically adjusted in accordance with the variations in the electric current.

2,473,465—Apparatus for Improving the Operation of Oxygen Cutting Torches—Paul L. Betz, Baltimore, Md. assignor to Consolidated Gas Electric Light and Power Company of Baltimore, Baltimore, Md., a corporation of Maryland.

In the patented device separate passages are provided for the flow of preheat oxygen and cutting oxygen. A special fuel passage is provided and valves are provided on the torch for controlling the flow of cutting oxygen and preheat oxygen.

2,473,575—Resistance Welding System—John W. Dawson, Auburndale, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

Dawson's welding system includes an energy storage device which has means for supplying energy provided therefor and a welding load is also provided. Means are present in the system for discharging the energy stored in the storage device into the welding load. A power source for supplying energy to the load is provided and means connect such power source to the load upon substantial discharge of the storage device.

2,473,576—Welding System—John W. Dawson, West Newton, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

In this welding system, a transformer is provided having a core comprising a frame portion and a shunt portion bridging the frame portion whereby the core defines a plurality of magnetic paths. Unidirectional fluxes are established through magnetic paths including the shunt portion and the frame portion and a secondary winding is superimposed on the primary winding and adapted to be connected across a resistance-welding load. The frame portion has a third winding adapted to be connected across a source of alternating current to establish alternating fluxes through magnetic paths including the frame portion but excluding the shunt portion.

2,473,600—Coating Work with an Electron-Emissive Material to Improve Inert Gas-Shielded Refractory-Electrode Alternating-Current Arc Welding

2,473,601—Gas Shielded Direct-Current Arc Welding—Roscoe R. Lobosco, Elizabeth, N. J., assignor to The Linde Air Products Co., a corporation of Ohio.

These patents relate to a welding method wherein the work is coated with an electron emissive material composed of an alkaline-earth metal, and a substantially nonconsumable electrode is positioned adjacent the work. The electrode and the work and the space there between is surrounded by an inert monatomic gas, and an alternating-current welding arc is set between an electrode and the work. For direct-current welding, the metal is of negative polarity and the electrode is positive.

2,473,633—Method of Welding Fins to Tubular Members by Electric Re-

SISTANCE WELDING—John W. Brown, Jr., Lakewood, Ohio, assignor to Brown Fintube Co., Elyria, Ohio, a corporation of Ohio.

This welding method applies to welding fins with a current conducting base portion to the inner surface of a current conducting tubular member.

2,473,634—ELECTRIC RESISTANCE WELDING METHOD—John W. Brown, Jr., Lakewood, Ohio, assignor to Brown Fintube Co., Elyria, Ohio, a corporation of Ohio.

Brown's welding method relates to a method of simultaneously forming a weld between two members of one pair of metal members and another weld between two members of another pair of metal members with a single pair of roller welding electrodes. A series of individual spot welds are provided.

2,473,668—ELECTRIC RESISTANCE WELDING METHOD—Oral Welsh, Elyria, Ohio, assignor to Brown Fintube Co., Elyria, Ohio, a corporation of Ohio.

Welsh's patent relates to patent No. 2,473,634 and comprises a modification of the welding method disclosed therein.

2,473,772—ELECTRIC STORED ENERGY RESISTANCE WELDING SYSTEM—Alfred Vang, New York, N. Y.

In this system a pair of solenoids are associated to form a transformer and an armature in one of the solenoids urges a pair of electrodes provided in the system together. The secondary of the transformer is adapted to supply a resistance welding current to the electrodes whereas the primary of the transformer is connected to an abruptly intereceptible source of current. The only iron in the transformer is in the armature.

2,473,799—CONDENSER WELDING SYSTEM—Hans Klemperer, Belmont, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

The condenser welding system of the patent includes a plurality of capacitors and means are provided for charging the capacitors and include a source of alternating voltage and a plurality of grid-controlled gaseous discharge devices. A first and a second capacitor are connected for discharge through the load circuit and means are connected to the second capacitor and coupled to the grids of the discharge devices during discharge of such capacitor. This latter connection is provided so that the voltage across the second capacitor is applied to the grids of the discharge devices during the discharge thereof so that such devices are rendered nonconducting

2,473,858—METHOD AND APPARATUS FOR WELDING STRUCTURAL CAGES

2,473,859—METHOD AND APPARATUS FOR WELDING STRUCTURAL CAGES—Adolf G. Butler, Hawthorne, Calif., assignor to American Pipe & Construction Co., Los Angeles, Calif., a corporation of Delaware.

Specialized apparatus of the character indicated in the titles are covered in these patents.

2,473,871—ELECTRIC ARC WELDING—Harry Edels, Stafford, England, assignor to The English Electric Company Ltd., London England, a British company.

This welding apparatus is adapted to weld a pillar to a magnetic surface and includes means for engaging the surface and means for holding the pillar movable on the support means. Additional means are present to render substantially symmetrical the magnetic field in the surface material in immediate proximity to the arc.

These means include an electromagnet slidably mounted on the support means.

2,473,886—BRAZING ALLOY—Frederick C. Hull, Pittsburgh, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania

The brazing alloy of the patent consists of copper, tin and zinc in certain specified amounts shown in a graph forming part of the patent

2,473,915—HEATING AND WELDING SYSTEM—Joseph Slepian, Pittsburgh and Alfred B. White, Edgewood, Pa., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This patent covers a special type of a power system for controlling flow of welding current. The discharge circuit of a condenser provided is adapted to produce a relatively high-frequency oscillation discharge of the condenser through an inductive load device forming part of the circuit.

2,473,917—ALTERNATING CURRENT ARC WELDING SYSTEM—Emil F. Steinert, Williamsville, and Charles H. Jennings, Buffalo, N. Y., assignors to Westinghouse Electric Corp. East Pittsburgh, Pa., a corporation of Pennsylvania.

This welding system includes a welding transformer for supplying welding current to a welding circuit and a capacitor is connected in shunt circuit relation with the welding circuit between the transformer and the arc. A resistor is connected in series circuit relation with the capacitor to reduce the arc noise without appreciably reducing the stabilizing effect of the capacitor.

2,473,927—APPARATUS FOR AND METHOD OF PERCUSSIVE WELDING—Alfred B. White, Murrysville, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This welding method comprises prepositioning a pair of metallic members with surfaces in contact, passing an electric discharge from a condenser between the plates sufficient to produce a fluid condition of the members at the contacting surfaces. A relatively sharp blow is applied to at least one of the members so as to force one member against the other member and bring the contacting surfaces together between the peak and the end of the first half cycle of the condenser discharge.

2,473,928—ARC WELDING SYSTEM—Alfred B. White, Murrysville, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

The arc-welding system of White's patent includes a welding transformer which has a secondary winding for connection to the arc-welding circuit. A reactance device is connected in series circuit relation with the secondary winding and the arc, and a capacitor is connected in shunt circuit relation with the secondary winding intermediate the reactance device and the voltage source. The capacitor is adapted to maintain substantially continuous arc with an open circuit secondary voltage of a specified amount.

2,474,023—METHOD OF GAS-SHIELDED ALTERNATING CURRENT ARC WELDING—Richard F. Wyer, Rexford, N. Y., assignor to General Electric Co., a corporation of New York.

In this welding method, a substantially nonconsumable metallic electrode is provided for fusing a metal and a gas such as argon or helium is supplied about the arc and the metal thereadjacent. The arc is energized from a source of alternating current having a voltage greater than the voltage at or below which complete rectification of current flow through the arc occurs. The voltage is great enough to cause current flow in both directions through the arc.

2,474,075—WELDING APPARATUS—Hyrum M. Talley, Alhambra, Calif.

This welding apparatus includes a resilient arm pivotally mounted adjacent a supporting means, which means are rotatable and adapted to carry the work to be welded. The resiliency of the arm permits it to be swung toward the work for position beyond a stop provided for limiting movement thereof. A hopper is carried by the arm and contains flux for discharge against the work, and means for feeding the welding electrode through the hopper and the flux therein are also provided.

2,474,129—WELDING APPARATUS—Vernon N. Tramontini—Indianapolis, Ind., assignor to Stewart-Warner Corp., Chicago, Ill., a corporation of Virginia.

In this patent welding apparatus is disclosed for making small diameter circular welds by a resistance welding operation.

SECTION ACTIVITIES

Prepared by C. M. O'Leary

Arizona

Organization meeting of the Arizona Section was held on Apr. 12, 1949, under the guidance of J. G. Magrath, Executive Secretary of the A.W.S.

The following were selected as the Activating Committee: A. W. Tesmer, Chairman; W. F. Fisher, Publicity; Gus Waago, Secretary; F. M. Aspey, Treasurer; J. F. Stacy, Membership; W. E. Riley, Program; and Ralph Smith, Arrangements.

The Activating Committee met each Monday night at the new Arizona Welding Equipment Co.'s building beginning May 2, 1949.

The first regular meeting of the Arizona Section was held at the Reynolds Metals Plant in Phoenix, at 7:30 P.M. on June 8, 1949. With the able guidance of Art Tesmer and the facilities of the Reynolds Metal Plant the first meeting proved to be a success.

After the preliminary business of the meeting the following officers were introduced to members of the Section in the order listed: F. M. Aspey, Treasurer; Allen F. Hansen, Secretary; Gus Rau, 2nd Vice-Chairman; J. Johnson, 1st Vice-Chairman; and R. A. Hoffman, Chairman.

The following Executive Committee Chairmen were also introduced. A. W. Tesmer, By-Laws; J. F. Stacy, Membership; Gus Waago, Hospitality; William Fisher, Publicity; Hal Savage, Program; William Giezel, Education; Ralph Smith, Arrangements; and Walter Riley, Technical Representative.

These officers were nominated and elected by the members present. The Activating Committee was discharged after due recognition of their work.

A short talk on the problems involved in bridge building was given by Mr. Hoffman after which the meeting was then thrown open to general discussion on future meetings. It was the opinion of the group to continue meetings throughout the summer months.

Chattanooga

The following officers have been elected by the Chattanooga Section for 1949–50: Chairman, J. W. Kelker, Jr., Combustion Engineering-Superheater, Inc.; 1st Vice-Chairman, W. L. Herbst, Lincoln Electric Co.; Secretary-Treasurer, George L. Tepley, Chattanooga Welders Supply Co.; Executive Committee—L. F. Pohl, Claude E. Phillips, Louis S. Chambless, James F. McElwee, Jr., and Pembroke O. Leach.

Annual Meeting of the Section was held on June 3rd at the Chattanooga Golf and Country Club.

Los Angeles

The regular dinner and meeting of the Los Angeles Section were dispensed with in lieu of a plant inspection trip on Thursday evening, May 19th, starting at 8 P.M. Host was Bethlehem Pacific Coast Steel Corp. in Los Angeles. Approximately 150 members and guests were conducted in groups through the plant's operating departments. The tour followed production flow, starting with the raw minerals and charge metal consisting of scrap and pig. Remelting equipment consisted of spectacular electric furnace and open hearths. All production from the blooming mill was being channeled to the rod mill, it being the only finishing department in operation as the structural mill was in process of roll change-over for production of shapes. The rod mill was particularly impressive in its speed increase from start to finish of nearly one mile per minute. Safety consciousness of the host was indicated by warning signs and guards, safety record score boards for each department, and care of guests by issuance of safety goggles to be worn while on tour.

All attending the tour were particularly appreciative of the thoughtful, courteous actions of the host's representatives who guided the tourists through and described the plant's interesting operations.

"Old Timers Night" was celebrated on Thursday evening, June 16th, with dinner at Scully's restaurant. Section Chairman E. O. Williams opened the program by introducing each past chairman. This being the last meeting for the 1948–49 officers, Mr. Williams gave a résumé of the season's activities, including participation in the extremely successful Western Metals Congress. Activities of each officer and committee chairman were recounted and the chairmen and members commended for their contributions toward making this a most successful year.

Nominating Committee Chairman C. P. Sander was called upon to report on the elected officers for the ensuing year. Officers are as follows: Chairman, Charles Haynes, C. F. Braun & Co.; Vice-Chairman, C. T. Sweitzer, Southern California Gas Co.; Secretary-Treasurer, Chas. Johnston, Victor Equipment Co.

The Gavel of Authority was passed to Mr. Sweitzer who introduced the speaker, Dr. A. E. Flanigan, Assistant Professor of Engineering, University of California in Los Angeles, who spoke on the subject "Effect on Notch Sensitivity of Low-Temperature Cooling Rates." Described briefly was the discovery in the U.C.L.A. Laboratories of this most interesting field concerning low-temperature cooling rates. The effect of cooling rates through temperatures in excess of 1000°F. has long been recognized; however, the research work providing material for this evening's talk was the result of tests conducted from 800°F. downward. Specimens consisted of E6010 electrode deposited on A-285C plate. Test results were recorded from notched longitudinal bend tests. Slides were shown exhibiting graphical test data, appearance of test specimens and testing apparatus. Data presented included startling evidence that internal cracking is produced by high cooling rates at low temperatures. Results of this research work are to be published soon so as to provide industry with a new approach to complicated welding problems. The speaker solicited comments of the group on the subject and its relation to welding fabrication problems. The professor from U.C.L.A. is one of the Section's favorite speakers and they look forward to a return engagement and another thought-provoking presentation.

New York

The New York Section held its Annual Smoker on May 6th at the Building Trades Employees Club. Over 300 members and guests attended the affair.

Announcement was made of the new officers for the 1949–50 season as follows: Chairman, G. W. Place, American Bureau of Shipping; 1st Vice-Chairman, G. L. Baker, Westinghouse Electric Corp.; 2nd Vice-Chairman, H. R. Clauser, Materials and Methods Pub.; Secretary-Treasurer, S. T. Walter, Air Reduction Sales Co.; Members-at-Large—A. E. Poole, The Hallen Co. (1-yr. term); J. L. Cahill, New York Navy Yard (2-yr. term); Prof. O. H. Henry, Polytechnic Institute of Brooklyn, A. M. Setapen, Handy and Harman, John Haydock, Design News Pub., and E. W Axtheim, The Linde Air Products Co. (3-yr. terms).

Brookhaven National Laboratory at Upton, L. I., N. Y., was visited by 200 members of the New York Section and their guests on Saturday, June 4th. Over 50 women were in the party.

The Laboratory is an atomic research project operated by Associated Universities, Inc., comprising representatives of Harvard, M.I.T., Yale, Rochester, Cornell, Columbia, Princeton, Pennsylvania and Johns Hopkins Universities, under a contract with the Atomic Energy Commission. It represents an investment of 25 million dollars devoted to research in nuclear physics and its application to industry, biology, medicine, metallurgy and other sciences. It comprises 6000 acres, numerous buildings, about 200 scientists and a staff of 1000 technicians and other help.

The program for the day included the following:

10:45 A.M. Assembly at the Research Staff Bldg. for registration, and distribution of literature.

11:00 A.M. Representatives of Associated Universities or the Laboratory Staff briefed the visitors on the following topics:

(*a*) Organizational structure of Associated Universities
(*b*) Research projects in progress
(*c*) The Brookhaven Reactor and associated equipment
(*d*) Welding aspects of the nuclear reactor
(*e*) Safety factors in atomic energy plant operations

After luncheon, seven parties were organized, each monitored by two members of the Inspection Committee under the guidance of a member of the Laboratory staff who escorted them to each of the following major installations:

Guided inspection of seven major laboratories, including:
Meteorology Installations
Accelerator Laboratory
Cloud Chamber Laboratory
Biology Laboratory
Cyclotron Site
Chemistry Laboratory
Instrumentation and Health Physics Laboratory

Gas and electric welding, brazing and silver soldering are being widely used in the construction of numerous devices required by the various laboratories.

Practically every laboratory has its own department for the fabrication of special instruments and devices not available commercially and, in addition, there is a General Machine Shop manned by precision machinists and tool makers to which sketches are sent for the machining of parts too large to be handled by the local shops.

The members of the New York Section and their guests were deeply impressed by repeated evidence of the many skills in science and industry being utilized as well as the resourcefulness and patience of the personnel applying themselves diligently and with obvious enthusiasm to the many research projects in hand.

The arrangements for the inspection trip were handled by Charles Kandel, a past-chairman of the New York Section, assisted by John K. Anderson and C. E. Alexander.

Portland

Twenty-four members and guests met at 5:00 P.M. on June 14th to make the tour of the Alcoa Plant at Vancouver, Wash. The tour ended at 6:30 P.M. in the dining room at the plant where a very fine steak dinner with all the trimmings was served by Chief-Cook Lewin and his staff.

Chairman Crumley introduced Norman Perser who made the tour possible. He in turn introduced Messrs. Danner, Noble and Scott who acted as guides and explained the process of making aluminum ingots.

Announcement was made of the election of the following officers: Chairman, Joe Crumley; Vice-Chairman, W. C. Smith; Secretary, C. J. Daniels; Treasurer, Ed Weil; Directors for two years—Gene Quintieri, Roy Haindel and Walt Lottis.

A picture was then shown by Mr. Perser on the manufacture of aluminum, which was very educational and explained many of the new steps in the manufacture of the finished products.

This was the final meeting of the 1948–49 season. The next meeting will be held in September.

Rochester

The May meeting, which was the last meeting of the season, was held on the 16th, and was most successful from a social and entertainment standpoint. Norman Sehm, magician and escape artist, provided the feature show. Good movies were shown and an excellent buffet lunch was served. Many door prizes were also awarded. Election ballots were counted and the following officers were declared elected for the 1949–50 season: Chairman, Walter Kazoroski, Consolidated Machine Tool Co.; Vice-Chairman, Herbert Fetter, Rochester Welding Works; Secretary-Treasurer, Walter Dick, Eastman Kodak Co.; Executive Committee—Fred Hall, Harry Stoler, Edward Jones, Harvey Ainsworth, Paul Ecklund, Robert Jackson, William Conley and Gordon Kane.

Mr. Kazoroski presented the Past-Chairman Pin to the retiring chairman, Mr. Hall, and congratulated him on the successful season just closed. Mr. Hall in turn wished the new chairman success in the year to come and thanked the officers and members of the Section for their fine spirit of cooperation.

Salt Lake City

A temporary organization has been set up in Salt Lake City and is functioning with Ed Fraser of Chicago Bridge as Chairman; Jay Gould of Geneva Steel, Vice-Chairman; Prof. Kemp of the U.S.A.C., Vice-Chairman; and Paul Ownby of Lang Co., Secretary. Jack Jones is Chairman of the Membership Committee.

At the opening meeting, a welding clinic was held sponsored by Pameco and conducted jointly by John Moeller and Jack Jones. A sound film was shown through the courtesy of the A. O. Smith Corp. telling the story of their pipe-line operation. This film was most enthusiastically received.

Appreciation was expressed to Prof. Gilbert S. Schaller of the University of Washington for his excellent presentation.

The first regular meeting of this Section was held on Thursday, June 9th, at Temple Square Hotel. Dinner speaker was Sid Worthen, Director of Dale Carnegie. Mr. Worthen talked on "Enthusiasm." His talk was well received.

Technical speaker was C. Roldo Call, Sales Engineer, Eutectic Welding Alloys Corp. Mr. Call presented an interesting talk on the advantages of low-temperature welding.

Toledo

The Toledo Section closed its 1948–49 season with the Second Annual Get-Together and Annual Meeting.

The Get-Together was a "Stag" meeting held at the Northwood Inn at 6:30 P.M. on Thursday, May 12th. An excellent steak dinner with all the trimmings was enjoyed by all. Two nature and sports films were shown, after which, those who wished to play cards did so, while others just lounged and kibitzed.

The Annual Meeting, which is a pure business and social affair, terminated the 1948–49 season. It was held at the Commodore Perry Hotel on Wednesday, June 8th. Committee reports were read and election results announced as follows: Chairman, Sam W. Snell, Odland Iron Works, Inc.; 1st Vice-Chairman, V. L. Farnsworth, Farnsworth & Middlekauff, Inc.; 2nd Vice-Chairman, Shepard Kinsman, A. D. Sonneborn Co.; Secretary-Treasurer, Raymond Urzykowski, National Wire & Iron Co.; Board of Directors—A. H. Homrighaus, L. E. Boysel and G. L. Chandler, Members-at-Large.

The new Chairman, Sam W. Snell, presented the retiring chairman, E. V. Newman with a Past-Chairman's Pin, which is a token of appreciation for good services rendered.

LIST OF NEW MEMBERS

June 1 to June 30, 1949

ANTHONY WAYNE

Amick, Dale M. (B)

BIRMINGHAM

Clotfelter, R. E. (C)

BOSTON

Cushman, George R. (B)
Kokolski, Andrew (C)

BRIDGEPORT

Gray, Joseph George (C)

CHICAGO

Biggins, J. P. (C)
Hinkle, William R., Jr. (C)
Karnisky, B. (C)
Taylor, Arthur Walmsley (C)
Williams, C. E. (C)

DALLAS

Baker, Edwin A. (B)
Banks, Ralph H., Jr. (C)
Feltner, H. O. (C)

DETROIT

McGregor, James K. (B)
Stoneback, Howard E. (B)

HARTFORD

Allan, James W. (B)
Anderson, Howard C. (B)
Atherton, John (B)
Daly, E. J., 3rd (B)
Daly, M. J., 3rd (B)

INDIANA

Lohrber, Albert E. (B)

LEHIGH VALLEY

Howard, Donald B. (C)

LONG BEACH

Carl, John J. (C)

LOS ANGELES

Bajari, William R. (B)

MARYLAND

Matthews, L. H. (C)
McGuire, Joseph J. (C)
Phelps, J. Milton (C)
Walters, R. M. (C)

NEW JERSEY

Peterson, Clyde (C)

NEW YORK

Brower, William B. (C)
Grim, Charles Augustus (B)
Kuprych, Stephen John (C)

NIAGARA FRONTIER

Gantvoort, John M. (B)

NORTHWESTERN PA.

Giles, Paul M. (C)

OKLAHOMA CITY

Metzger, Henry J. (C)

PHILADELPHIA

Hopper, Arthur J. (B)

ST. LOUIS

Cummings, Charles E. (C)
Meyer, Walter B. (B)

SAN FRANCISCO

Kewley, Monte L. (B)

SOUTH TEXAS

Reagan, John M. (C)
Richardson, L. D. (B)

WASHINGTON

Ross, Clarence Leroy (D)
Stratton, Richard M. (C)
Tooke, Charles M. (B)

WESTERN MASS.

Bissonnette, Victor L. (B)

NOT IN SECTIONS

Brown, Edwin S. (B)
Dansie, George W., Jr. (B)
Fielder, Alfred (C)
Jenkins, D. S. (B)
Jones, J. R. (B)
Lang, J. Robert (B)
Lapp, Wm. A. (B)
McCune, Paul (B)
Monson, Charles E. (D)
Ownby, Paul W. (B)
Potts, Ray L. (B)
Powell, Leo C. (B)
Ray, Arthur W., Jr. (B)
Shoor, Abraham (B)

Current Welding Literature

(Continued from page 758)

Joining Operations, R. S. Inglis. Steel, vol. 124, no. 21 (May 23, 1949), pp. 90–93, 111, 113.

Electric Welding. Resistance Welding, J. Hutchinson. Light Metals, vol. 12, no. 133 (Feb. 1949), pp. 101–104; (discussion), pp. 104–105.

Electroplated Products. Joining Coated Metals—Survey of Processes and Applications, D. V. Beatson. Metal Industry, vol. 74, no. 13 (Apr. 1, 1949), pp. 251–253.

Gas Welding Torches. Precision-Made Torches for Better Welding, R. G. Paul. Western Machy. & Steel World, vol. 40, no. 2 (Feb. 1949), pp. 70–73, 90, 98.

Industrial Plants, Welded Steel. Girders Act in Unison to Support Cranes at Two Levels. Eng. News-Rec., vol. 142, no. 15 (Apr. 14, 1949), pp. 62–63.

Iron Castings. Some Aspects of Welding of Cast Iron. Welder, vol. 18, no. 99 (Jan.–Mar. 1949), pp. 2–5.

Iron Castings. When to Braze or Fusion Weld Cast Iron, K. H. Koopman. Industry & Welding, vol. 22, no. 2 (Feb. 1949), pp. 34, 36, 38, 40–41, 62.

Jacks. Arc-Welded Jack Steps Up Production, H. P. Krull. Welding Engr., vol. 34, no. 4 (Apr. 1949), pp. 44–45.

Jigs and Fixtures. Welded Construction Drilling Jig, R. Mawson. Iron Age, vol. 163, no. 20 (May 19, 1949), pp. 94–95.

Light Metals. Welding of Aluminium and Its Alloys, E. G. West. Engineering, vol. 167, no. 4341 (Apr. 8, 1949), pp. 317–319; no. 4342 (Apr. 15), pp. 341–342.

Locomotive Manufacture. Improved Manufacturing Methods at Crewe Locomotive Works, I. C. Forsyth. Engineering, vol. 167, no. 4338 (Mar. 18, 1949), pp. 259–260.

Locomotives, Mine. Tires. Rebuilding Wheels of Mine Locomotives. Welding Engr., vol. 34, no. 4 (Apr. 1949), pp. 38–39.

Natural Gas Pipe Lines. Modern Gas-Pipe-Line Construction, F. E. Richardson. Oil & Gas J., vol. 48, no. 1 (May 12, 1949), pp. 99–100, 103–104.

Natural Gas Pipe Lines. Spacing in Pipe-Line Welding, L. J. Cunningham. Oil & Gas J., vol. 47, no. 52 (Apr. 28, 1949), p. 90.

Oil Tankers, Reconditioning. Repairs to All-Welded Tanker "Afghanistan", A. L. White. Inst. Welding—Trans., vol. 12, no. 2 (Apr. 1949), pp. 37–45.

Oxygen Cutting. New Manual Oxygen Cutter. Shipbldr. & Mar. Engine-Bldr., vol. 56, no. 484 (Apr. 1949), pp. 251–252.

Oxygen Cutting Templates. Rod Template for Stack Cutting, P. Glanzer. Welding Engr., vol. 34, no. 3 (Mar. 1949), p. 51.

Penstocks, Welded Steel. From Plate to Penstocks, F. M. Burt. Welding Engr. vol. 34, no. 4 (Apr. 1949), pp. 40–43.

Pipe Lines, Welding. Conductors Stress-Relieve Welds, C. C. Roberts. Am. Mach., vol. 93, no. 7 (Apr. 7, 1949), p. 97.

Pipe Lines Across Desert, E. Sterrett. Welding Engr., vol. 34, no. 4 (Apr. 1949), pp. 33–35.

Pressure Vessels. Welded Pressure Vessels, N. Gross. Welder, vol. 18, no. 99 (Jan.–Mar. 1949), pp. 8–11.

Rails, Welding. Long Rails in South Africa, A. F. Bruyns-Haylett. Ry. Gaz., vol. 90, no. 6 (Feb. 11, 1949), pp. 154, 163.

Riveted Joints, Testing. Rivet Flexibility and Load Diffusion, E. H. Mansfield. Aircraft Eng., vol. 21, no. 242 (Apr. 1949), pp. 96–98, 116.

Shipbuilding, Welding vs. Riveting. Ship Structural Members—Pt. IV. G. J. Jensen. Shipbldr. & Mar. Engine-Bldr., vol. 56, no. 485 (Annual Int. No.) (Apr. 1949), pp. 307–310.

Soldering Aluminum, J. F. Whiting. Can. Metals & Met. Industries, vol. 12, no. 4 (Apr. 1949), pp. 22–23.

Soldering. New Self-Heating Tape Simplifies Soldering Operations, R. B. Stanton. Matls. & Methods, vol. 29, no. 4 (Apr. 1949), p. 57.

Temperature Control Apparatus. Electronic Measurement and Control of Heat, J. H. Jupe. Electronic Eng., vol. 21, no. 253 (Mar. 1949), pp. 94–97.

Thermit Welding. Mill Housings—Successful Repairs by Thermit Welding. Iron & Steel, vol. 22, no. 4 (Apr. 1949), pp. 124–126.

YOUR GUIDE TO BETTER WELDING

HERE is a handy data sheet that can help you get good results in Gas Welding, Arc Welding or Furnace Brazing. It lists the different types of jobs you might want to do and shows which Revere Welding Rod will give best results in each use. This data sheet is free for the asking—write for your copy today.

Revere Welding Rods are among the many copper and copper alloy products made by Revere Copper and Brass Incorporated. As with other Revere products, constant research, modern production equipment, and rigid quality control have made Revere Welding Rods unsurpassed in quality and performance.

Revere Welding Rods include: Revere 456 Low-Fuming Bronze Welding Rod, Revere Bronze 380, Manganese Bronze, Herculoy, Phosphor Bronzes, Brass (Brazing Rod), Silicon Deoxidized Copper and Electrolytic Copper. All come in 100-pound cases or in 25-pound cartons, net weight, and are stocked by Revere Welding Rod Distributors in all parts of the country.

REVERE

COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

230 Park Avenue, New York 17, N. Y.

• • •

Mills: Baltimore, Md.; Chicago, Ill.; Detroit, Mich.; New Bedford, Mass.; Rome, N.Y.

Sales Offices in Principal Cities, Distributors Everywhere.

TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

30th Annual Meeting
week of October 16, 1949

CLEVELAND HOTEL, CLEVELAND, OHIO

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week in the Cleveland Public Auditorium

SUNDAY AFTERNOON, OCTOBER 16th—3 TO 5 P.M.

Registration and Get-Together

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the session. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 17th—9:30 A.M.

Three Simultaneous Sessions

STRUCTURAL DESIGN
Ball Room

Chairman—LaMOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—F. L. PLUMMER
Hammond Iron Works

Design and Construction of a Modern Welded Deck Girder Highway Bridge
by NED L. ASHTON, State University of Iowa

Economical Design of Welded Buildings
by ROBERT E. ROBERTSON, JR., Saxe, Williar & Robertson, Engineers and Consultants

Proposed Design of Welded Rigid Frames for New York Subways
by MARTIN P. KORN, Consulting Engineer

A Strain Gage Test and Analysis of an Eighty-Foot H-Section Welded Truss
by A. WAIDELICH, The Austin Co.

PRESSURE VESSELS
Red Room

Chairman—A. C. WEIGEL
Combustion Engineering-Superheater, Inc.

Co-Chairman—G. M. TREFTS
Farrar & Trefts, Inc.

Importance of Design in Construction of Tanks and Pressure Vessels
by WALTER SAMANS, Chairman, Pressure Vessel Research Committee

Trends in Fabrication by Welding
by S. V. WILLIAMS, Struthers-Wells Corp.

Inert-Gas-Shielded Arc-Welding Aluminum Pressure Vessels
by A. J. HOPPER, Welding Engineers, Inc.

Notch Sensitivity of Mild Steel Plates
by A. B. BAGSAR, Sun Oil Co.

HARD FACING AND FLAME HARDENING
Rose Room

Chairman—R. P. TARBELL
Scott-Tarbell, Inc.

Co-Chairman—G. H. MEYER
The Linde Air Products Co.

Automatic Electric Hard Facing
by TURNER G. BRASHEAR, JR., Leader Welding and Manufacturing Co.

Hot Hardness of Hard-Facing Alloys
by HOWARD S. AVERY, American Brake Shoe Co.

Hard-Facing Applications in the Steel Industry
by J. J. BARRY, Air Reduction Sales Co.

Flame Hardening of Large Diameter Rounds
by S. SMITH, Air Reduction Sales Co.

MONDAY AFTERNOON, OCTOBER 17th—2:00 P.M.

Three Simultaneous Sessions

NONFERROUS METALS
Red Room

Chairman—O. B. J. FRASER
The International Nickel Co., Inc.

Co-Chairman—F. G. FLOCKE
The Thornton Company

Arc Welding of Molybdenum
by I. S. GOODMAN, Westinghouse Electric Corp.

The Welding of High-Nickel Alloys to Other Metals
by G. R. PEASE and H. B. BOTT, The International Nickel Co., Inc.

Seam Welding Monel Metal to Steel
by ERNEST F. NIPPES, ALLAN R. PFLUGER and GERALD M. SLAUGHTER, Rensselaer Polytechnic Institute

EDUCATION
Rose Room

Chairman—R. A. WYANT
Rensselaer Polytechnic Institute

Co-Chairman—GILBERT DOAN
Lehigh University

Welding in Engineering Education
by R. S. GREEN, The Ohio State University

Formal Training of Welding Personnel
by ALLEN C. TYLER, Acting Dean, LeTourneau Technical Institute

Continuation of Study of Welding and Welding Processes
by FRANK W. SCOTT, Marquette Mfg. Co., Inc.

RESEARCH
Ball Room

Chairman—ROSS J. YARROW
Republic Structural Iron Wks. Co.

Co-Chairman—L. K. STRINGHAM
The Lincoln Electric Co.

The Statistical Part in Welding Investigations
by B. B. DAY, Statistician, Director's Staff, U. S. Naval Engrg. Exp. Station

Brittle Failure and Size Effect in a Mild Steel
by K. J. STODDEN and E. P. KLIER, The Pennsylvania State College

Weld-Peening Investigations
by J. LYELL WILSON, American Bureau of Shipping

MONDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series

Parlor B, 3rd Floor Public Auditorium

Chairman—DR. G. E. DOAN
Lehigh University

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

MONDAY EVENING—8:00 P.M.

Ball Room

Chairman—GEORGE N. SIEGER, President
American Welding Society

Co-Chairman—M. S. SHANE, Chairman
Convention Committee

AWARDS OF PRIZES AND MEDALS

1949 ADAMS LECTURE

The Advantages and Disadvantages of Electric Welding as a Means of Fabricating Steel Structures, by W. M. WILSON, University of Illinois

TUESDAY MORNING, OCTOBER 18th—9:30 A.M.

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH
Ball Room

Chairman—CAPT. C. M. TOOKE
Bureau of Ships, USN

Co-Chairman—
COMDR. R. D. SCHMIDTMAN
U. S. Coast Guard

Introduction

The Work of the Ship Structure Committee
by REAR ADMIRAL ELLIS REED-HILL, U.S.C.G. Chairman, Ship Structure Committee

Factors Influencing the Tensile Behavior of Notched Flat Plate Specimens
by PROF. S. T. CARPENTER and CAPT. W. P. ROOP, U.S.N. (Ret.), Swarthmore College

Correlation of Test Results
by DR. C. F. TIPPER, University of Cambridge, England

Tests of Slotted Steel Plates
by E. M. MacCUTCHEON, C. L. PITTIGLIO, David Taylor Mode Basin, U.S.N., and R. H. RARING National Research Council

Further Study of the Navy Tear Test
by NOAH KAHN and EMIL IMBEMBO, New York Naval Shipyard

RESISTANCE WELDING
Red Room

Chairman—T. EMBURY JONES
Precision Welder & Machine Co.

Co-Chairman—R. E. POWELL
Western Electric Co.

Material Consumption Rates and Flashing Characteristics
by WILLIAM N. PLATTE, Westinghouse Electric Corp.

Factors Affecting the Quality of Production Flash Welding
by E. SIRABIAN, Arnold, Schwinn & Co.

The Homopolar Generator Stored-Energy System for Resistance Welding
by THOMAS J. CRAWFORD, Progressive Welder Co.

Circuit Analysis of Frequency Changer Welders
by W. K. BOICE, General Electric Co.

MACHINERY WELDING
Rose Room

Chairman—CHAS. H. JENNINGS
Westinghouse Electric Corp.

Co-Chairman—L. S. McPHEE
Whiting Corporation

Weldment Design and Engineering Practice
by ANTHONY K. PANDJIRIS, Pandjiris Weldment Co.

Welding of Alloy Steel Shovel Buckets
by E. R. McCLUNG, Lukenweld, Inc.

Lowering Cost of Welded Construction
by OMER BLODGETT, The Lincoln Electric Co.

Aluminum Bronze Electrodes
by J. A. CUNNINGHAM, J. A. Cunningham Equipment, Inc.

TUESDAY AFTERNOON, OCTOBER 18th—2:00 P.M.

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH
Ball Room

Chairman—FINN JONASSEN
The Committee on Ship Steel, National Research Council

Co-Chairman—J. LYELL WILSON
American Bureau of Shipping

Distribution of Relative Ductility in Steel Weldments
by L. J. KLINGLER and L. J. EBERT
Case Institute of Technology

Bend and Tensile Specimens Used as Indices of Performance and Weldability
by C. B. VOLDRICH and P. J. RIEPPEL, Battelle Memorial Institute

Effect of Cyclic Stress on Impact Transition Curve of Ship Steels
by PROF. J. M. LESSELLS and H. E. JACQUES, Massachusetts Institute of Technology

Axial Tension Impact Tests of Structural Steels
by W. H. BRUCKNER and N. M. NEWMARK, University of Illinois

RESISTANCE WELDING
Red Room

Chairman—R. H. ABORN
U. S. Steel Corp.

Co-Chairman—R. T. GILLETTE
General Electric Co.

Spotweld Consistency Studies
by JULIUS HEUSCHKEL and H. C. BITZER, Westinghouse Research Labs.

Spot Welding Heavy Gage Structural Steel
by ERNEST F. NIPPES and R. F. UNDERHILL, JR., Rensselaer Polytechnic Institute

Slope Control and Its Effect on Spot and Projection Welding
by I. W. JOHNSON, General Electric Co.

MISCELLANEOUS
Rose Room

Chairman—L. C. BIBBER
Carnegie-Illinois Steel Corp.

Co-Chairman—J. J. CHYLE
A. O. Smith Corp.

Welding of Zinc-Base Die Castings
by ROLAND H. OGDEN, Alladin Rod & Flux Mfg. Co.

Silver Alloy Brazing Stainless Steel
by C. H. CHATFIELD and A. W. SWIFT, Handy & Harman

Magnaflux Inspection of Welded Storage Tanks
by F. A. UPSON, Standard Oil Company (Indiana)

High Energy Loading Method of Testing Steel Plate and Weldments
by G. S. MIKHALAPOV, Metallurgical Research and Development Co., Inc.

TUESDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series

Parlor B, 3rd Floor, Public Auditorium

Chairman—DR. G. E. DOAN
Lehigh University

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

TUESDAY EVENING, OCTOBER 18th—8 P.M.

PRESIDENT'S RECEPTION
Red Room

Subscription buffet dinner, pay-as-you-go bar, dancing, music, etc.

WEDNESDAY MORNING, OCTOBER 19th—9:30 A.M.

Three Simultaneous Sessions

APPARATUS
Red Room

Chairman—H. O. HILL
Bethlehem Steel Co.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Design Features of a Welding Generator with Controlled Reactance
by J. M. TYRNER, Air Reduction Sales Co., and O. KOBEL, G. D. Peters & Co. of Canada, Ltd.

Measurement of Flux Densities in Steels for Magnetic Particle Inspection
by T. E. HAMILL, Naval Gun Factory

Economical Arc Welding
by S. OESTREICHER, Harnischfeger Corp.

RESISTANCE WELDING
Ball Room

Chairman—WILSON SCOTT
Westinghouse Electric Corp.

Co-Chairman—B. L. WISE
National Electric Welding Mach. Co.

Fatigue Tests of Spot-Welded Mild Steel and Stainless Steel Sheets
by PROF. GEORGES WELTER, École Polytechnique, Montreal, Canada

Spot Welding Galvanized Steel
by M. L. BEGEMAN, MILLARD L. HIPPLE and L. CULLUM, JR., The University of Texas

Electrical Resistance Offered by Non-Uniform Current Flow
by W. B. KOUWENHOVEN, and WILLIAM T. SACKETT, JR., School of Engineering, The Johns Hopkins University

Design and Application of Portable Resistance Welding Tools
by C. H. DAVIS, JR., The Budd Co.

ALUMINUM
Rose Room

Chairman—G. O. HOGLUND
Aluminum Co. of America

Co-Chairman—DANA W. SMITH
The Permanente Metals Corporation

The Economy of Shielded Arc Welding of Aluminum
by FRITZ ALBRECHT, The Glenn L. Martin Company

Shear Strength Consistency of Spot Welds in Alclad 24 S-T3
by J. C. BARRETT, The Glenn L. Martin Company

Heliarc Welding of Aluminum Alloys
by F. H. STEVENSON, Modern Metal Spinning & Mfg. Co.

WEDNESDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series

Parlor B, 3rd Floor, Public Auditorium

Chairman—DR. G. E. DOAN
Lehigh University

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

WEDNESDAY AFTERNOON, OCTOBER 19th—2:00 P.M.

BUSINESS MEETING

BOARD OF DIRECTORS MEETING

WEDNESDAY EVENING—7:30 P.M.

SECTION OFFICERS CONFERENCE

UNIVERSITY CONFERENCE

THURSDAY MORNING, OCTOBER 20th—9:30 A.M.

Three Simultaneous Sessions

ARCS AND ELECTRODES
Red Room

Chairman—J. H. HUMBERSTONE
Air Reduction Sales Co.

Co-Chairman—O. T. BARNETT
Metal & Thermit Corp.

Arc Welding Metal Transfer Analyzer
by R. C. McMASTER, D. C. MARTIN and A. LEATHERMAN, Battelle Memorial Institute

Heat Effects in Anode Spots of High-Current Arcs
by DR. T. BENJAMIN JONES, Johns Hopkins University

Application of Mild Steel Welding Electrodes
by F. R. STRATE, Air Reduction Sales Co., and R. I. STROUGH, Arcrods Corp.

Energy Distribution in Electric Welding
by CLARENCE E. JACKSON and A. E. SHRUBSALL, Union Carbide & Carbon Res. Labs.

RAILROAD
Rose Room

Chairman—ROY F. JOHNSON
Pullman-Standard Car Mfg. Co.

Co-Chairman—A. G. OEHLER
Editor, Railway Mechanical Engineer

Evolution of the Welded Freight Car
by L. E. GRANT, Chicago, Milwaukee, St. Paul & Pacific Railroad Co.

Oxy-Acetylene Pressure-Welded Rail Saves Maintenance Costs
by LEM ADAMS, Oxweld Railroad Service Company

Arc Welding in Railroad Shops
by E. DiLIBERTI, Air Reduction Sales Company

Inert Gas Welding in Railroad Repair and Rehabilitation
by H. E. GANNETT, Chicago, Burlington & Quincy Railroad

WELDABILITY
Ball Room

Chairman—A. B. KINZEL
Union Carbide & Carbon Res. Labs.

Co-Chairman—R. E. SOMERS
Bethlehem Steel Co.

Strain Aging in Welding Low-Carbon Structural Steel
by W. H. BRUCKNER and S. W. SANDBERG, University of Illinois

The High-Frequency Notch Bend Test
by BELA RONAY, U. S. Naval Engrg. Exp. Station

Studies Concerning the Strain-Aging of Arc Welds in Mild Steel
by A. E. FLANIGAN, University of California, Los Angeles

Synthetically Heat Treated Specimens for Weldability
by ERNEST F. NIPPES and WARREN SAVAGE, Rensselaer Polytechnic Institute

THURSDAY EVENING—7:30 P.M.

Symposium—For ECONOMY IN PRODUCTION—WELD!

Parlor B, 3rd Floor, Public Auditorium

FRIDAY MORNING, OCTOBER 21st—9:30 A.M.

Three Simultaneous Sessions

INERT GAS WELDING
Ball Room

Chairman—C. B. VOLDRICH
Battelle Memorial Institute

Co-Chairman—C. A. LOOMIS
Bureau of Ships, USN.

Heliarc Welding in the Automotive Industry
by F. J. PILIA and R. H. BENNEWITZ, The Linde Air Products Co.

Inert Gas Shielded Metal Arc Welding Process
by A. MULLER, G. J. GIBSON and E. H. ROPER, Air Reduction Sales Co.

Automatic Heliweld Applications
by H. O. JONES, Air Reduction Sales Co.

Applications for Helium in Inert Arc Welding
by M. J. CONWAY, General Electric Co.

STAINLESS STEEL
Red Room

Chairman—W. O. BINDER
Union Carbide and Carbon Research Labs.

Co-Chairman—E. VOM STEEG
General Electric Company

Corrosion Resistance of Molybdenum Bearing Stainless Steel Weld Metals
by R. D. THOMAS, JR., and ANTON L. SCHAEFFLER, Arcos Corporation

Problems Associated with the Welding of Stainless Clad Steel
by PERRY C. ARNOLD, Chicago Bridge & Iron Co.

Resistance Welding Stainless Steel Truck-Trailer Body Components
by BYRON GATES, The Budd Co.

Stainless Steel Fabrication by Inert-Gas-Shielded Arc Welding
by CHARLES D. BONIFIELD, The Globe Company

GAS CUTTING
Rose Room

Chairman—J. J. CROWE
Air Reduction Sales Co.

Co-Chairman—
H. E. ROCKEFELLER
The Linde Air Products Co.

New Developments in Oxyacetylene Cutting Machines
by W. BEGEROW and A. H. YOCH, Air Reduction Sales Co.

Steel Warehouse Shape Cutting with Electronic Tracers
by WILLIAM O. SPRINGER, Joseph T. Ryerson & Son, Inc.

Flame Cutting
by JAMES T. LEWIS, Lewis Welding & Engineering Corp.

Powder Cutting and Scarfing Process
by C. W. POWELL, Republic Steel Corp.

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society and American Institute of Electrical Engineers American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, August, 1949

Effect of Plastic Strain and Heat Treatment

Progress report No. 3 on the effect of fabrication processes on steels used in pressure vessels. The effects on the tensile and notch properties of a rimmed and a killed steel are presented

by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston

FOREWORD

THIS is the third of a series of reports describing the results of work performed at Lehigh University for the Fabrication Division of the Pressure Vessel Research Committee of the Welding Research Council. The ultimate objective of this work is to furnish information about the effects of various fabrication operations, such as cold forming, postheating and welding, on the physical properties of steels used for pressure vessels. This is with the intention of setting up specifications for pressure vessel steels to insure desirable physical properties in the steels which are not covered in the present specifications.

The first major step toward this objective was an investigation of the effects of cold work and postheating on the properties of unwelded steel plates.

Previous progress reports[1, 2] have described essential preliminaries to the main program described herein.

C. J. Osborn was formerly Pressure Vessel Research Committee fellow at Fritz Engrg. Lab., Lehigh University, **Miss A. F. Scotchbrook** is Research Assistant at Fritz Engrg. Lab., Lehigh University, **R. D. Stout** is Associate Professor of Metallurgy, Lehigh University, **B. G. Johnston** is Director, Fritz Engrg. Lab., and Professor of Civil Engineering, Lehigh University, Bethlehem, Pa.

This paper was presented on Nov. 30, 1948, at a joint meeting of the Metals Engineering Division of the A.S.M.E. and the Pressure Vessel Research Committee of the Welding Research Council.

INTRODUCTION

Most pressure vessels are fabricated from plate material by hot or cold forming, and assembly by welding, with or without stress relief. All of these processes affect the strength, ductility and fracture characteristics of the steel plate, two factors being of particular importance. First, cold work and strain aging may increase the strength of the plate material; however, the effects of cold forming will usually vary considerably from point to point. Second, the notch properties of the material after fabrication cannot be predicted by tests on the as-received plates, except to say qualitatively that they probably deteriorated during the cold forming and welding operations and in subsequent strain aging. This uncertainty constitutes a threat to the safety of fabricated vessels, particularly when new forming methods or stress-relief treatments are attempted.

The present investigation is a study of both of these problems by systematically considering the important variables, beginning with a study of the effects of homogeneous cold work and proceeding to the effects of uniform heat treatment on cold-worked material.

The Lehigh slow notched-bend test, after careful investigation and consideration,[1] was adopted for this investigation. The Charpy test was also used since it still commands a wider degree of acceptance than any other notch test, and standard tensile tests were carried on concurrently with the notched tests.

MATERIALS

Plate Stock

Materials used in this series of tests were $1^1/_4$- and $^5/_8$-in. carbon-steel plates from two different heats, one an aluminum-killed heat of A.S.T.M. specification A-201 and the other a rimmed heat made to A.S.T.M. specification A-70 (now A-285). Complete heat records were included in a previous report.[2]

The variation of tensile properties and transition temperatures found within a heat of as-received plate material was thoroughly investigated.[2] The highest and lowest values and their difference for the same plate thickness and the same test direction were as follows:

0.505-in. tensile properties	*A-70*	*A-201*
% Elongation	40.9 − 37.3 = 3.6	42.5 − 33.5 = 9.0
% Reduction of area	62.4 − 56.3 = 6.1	63.2 − 54.8 = 8.4
ϵ_h	0.990 − 0.825 = 0.165	1.005 − 0.799 = 0.206
ϵ_a	0.185 − 0.178 = 0.007	0.229 − 0.166 = 0.063
ϵ_n	0.812 − 0.641 = 0.171	0.778 − 0.613 = 0.165
Upper yield point, psi.	30,600 − 29,400 = 1,200	31,850 − 28,900 = 2,950
Lower yield strength, psi.	27,950 − 26,000 = 1,950	31,200 − 28,000 = 3,200
True breaking stress, psi.	112,700 − 102,000 = 10,700	122,400 − 115,000 = 7,400
Nominal maximum, psi.	62,200 − 55,700 = 6,500	63,800 − 58,100 = 5,700

Charpy (Keyhole notch) transition values, ° F.

	A-70	*A-201*
Energy	57 − 34 = 23	−50 − −70 = 20
% Cleavage (T_B)	68 − 47 = 21	+25 − −10 = 35
% Contraction (T_N)	+8 − −6 = 14	−50 − −69 = 19

The apparently lower variation of some properties in the A-70 plate is not necessarily a true picture, since the results represent fewer tests than do the A-201 results.

In order to minimize these effects of within-heat variations, it was originally intended to take specimens from only the middle thirds of the ingots. This procedure was adopted in the case of the A-201 plates, but it was not practicable with the A-70 material because each plate represented a whole ingot and it was necessary to use plate-length strips to avoid excessive waste of material during cold working.* On the basis of the heat surveys mentioned above, it would be expected that the A-201 material used on the present investigation had comparatively uniform properties, but that there would be some variation within the A-70 material. However, most of the segregation observed in the A-70 ingots occurs in relatively small zones close to the top and bottom of the ingots, and no A-70 test pieces for the present investigation were taken from within at least 2 ft. of either end of the plate. In spite of these precautions, it is felt that where differences in tensile and transition values of the order noted above occurred, they cannot be attributed with surety to prestrains or postheats.

* See Progress Report No. 2[2], Fig. 1. A-201 as-rolled material came from plates 7433-T, 7432-B and 7436-B; A-201 normalized material came from plate 7434-B; A-70 as-rolled material came from plates 2 and 4, i.e., ingots 2 and 4.

Complete chemical analyses for both steels are given in Table 1.

Cold Work

Each of the as-rolled $1^1/_4$-in. plate materials described in the previous section was tested after the following cold forming treatments:

1. None
2. Permanent tension strain of 0.01 (1%) in direction of rolling
3. Permanent tension strain of 0.05 (5%) in direction of rolling
4. Permanent tension strain of 0.10 (10%) in direction of rolling
5. Permanent tension strain of 0.01 (1%) transverse to direction of rolling
6. Permanent compression strain of 0.01 (1%) in direction of rolling

Table 1—Chemical Composition of Materials

	*A-201 (Al-killed)**	*A-70 (Rimmed)*†
Carbon	0.15	0.20
Manganese	0.53	0.35
Sulphur	0.025	0.028
Phosphorus	0.020	0.018
Silicon	0.19	0.02
Nickel	0.05	0.10
Chromium	0.04	0.05
Copper	0.08	0.14
Tungsten	0.04	0.04
Vanadium	0.02	0.02
Molybdenum	0.01	0.01
Aluminum	0.026	0.021
Alumina	0.002	0.003
Nitrogen	0.003	0.003

* This composition applies to the center of ingot No. 9, i.e., to plate 7436-B. However, the composition for other A-201 plates used was almost identical, except that Al content was higher (0.04%).

† Both A-70 plates used in the present investigation were cast in the same group or cluster, so composition should be the same. Composition applies at center of ingot No. 2.

The $^5/_8$-in. material was tested only after treatments 1 and 3.

These strains were considered representative of the range of average plastic strains developed in actual fabrication processes.

Operations 2, 3 and 4 were performed by pulling strips 24 ft. long and 12 in. wide in a testing machine of 800,000 lb. capacity. Approximately 2-ft. lengths were discarded from each end of the 24-ft. strips to avoid us-

ing material within 12 in. of the grips. In addition to over-all deformation measurements, transverse lines scribed at 2-ft. intervals along each strip prior to stretching were measured after stretching, to determine the uniformity of the deformation. The results of these measurements are summarized in Table 2.

Table 2—Actual Nominal Tensile Strains in Rolling Direction

Measured strains on 2-ft gage lengths

	1% Intended		5% Intended		10% Intended	
Heat treatment, ° F.	*A-201*	*A-201**	*A-70*	*A-201*	*A-70*	*A-201*	*A-70*
None	1.2	1.0	1.0	5.1	5.9	10.4	11.2
500	1.3	1.3	0.9	5.2	5.1	10.4	9.2
800	1.5	1.3	1.2	5.1	4.3	10.3	8.5
1150	1.3	1.4	1.3	5.3	4.2	10.7	6.8
1600	1.6	0.8	1.4	5.7	6.3	10.6	14.5

* Mill-normalized.

Operation 5 was performed by pulling strips 72 in. long by 4 in. wide in a testing machine of 300,000 lb. capacity. By using the narrower strip and smaller testing machine, it was necessary to discard only about 9 in. from each end of the strips.

Operation 6 was performed by compressing small strips 12 to 14 in. long by 4 by $1^1/_4$ in. in a jig consisting of two banks of rollers to prevent buckling. The device is shown in Fig. 1. Strains were measured on both edges of the specimen during compression by means of a 10-in. Whittemore strain gage.

In addition to the as-rolled materials investigated, the A-201 mill-normalized plate was tested in conditions 1 and 2 above.

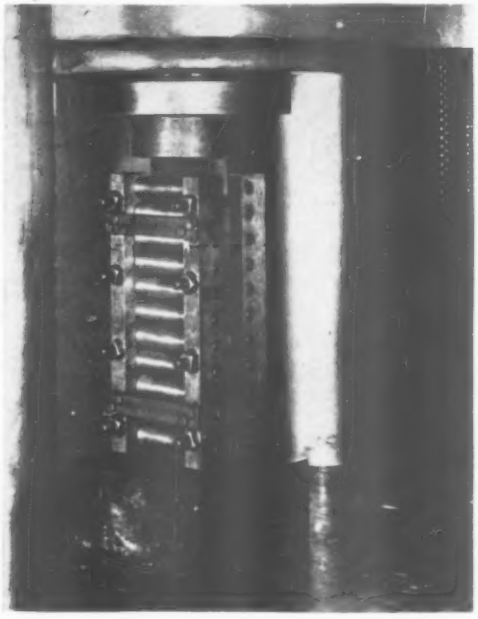


Fig. 1 Compression jig

Heat Treatment After Cold Work

Material in each of the cold-worked conditions described in the previous section* was tested after each of the following heat treatments, to simulate the indicated fabrication treatment:

1. Room temperature—no heat treatment
2. 500° F.—accelerated strain-aging
3. 800° F.—possible intermediate stress-relieving
4. 1150° F.—usual stress relieving
5. 1600° F.—normalizing

Cold-worked specimens were placed in a furnace held at the required temperature; this usually caused the furnace temperature to drop. When the furnace temperature regained its proper level, the specimens were held for 1 hour per inch of section, then removed and allowed to cool freely in air.

It will be noted in Table 2 that, in general, sections receiving most nearly the intended strain were tested in the as-strained condition, while sections in which the actual strain was most removed from the intended strain were used for the higher temperatures.

Small specimens were taken from each condition for micrographic study. Neither the strains nor the heat treatment to 1150° F. produced any evident change in microstructure. The 1600° F. treatment, however, refined the grain size from A.S.T.M. No. 7 to No. 9.

TEST PROCEDURES

Tensile Test

Standard 0.505-in. diameter tensile specimens were tested and autographic load-extension diagrams were obtained through the elastic and early plastic ranges. In this range a strain rate of 0.006 in. per minute was maintained. Beyond this, a true stress vs. natural strain curve was obtained by measuring the changing bar diameter at its minimum section.

In all cases duplicate tests were made, both parallel and transverse to the rolling direction.

Charpy Tests

Standard V-notch Charpy specimens were used to obtain transition curves and temperatures for all of the conditions described above. The long dimension of all specimens was parallel to the direction of overstrain and all notches were cut perpendicular to the plane of the plate. Notches were machined by milling and were cut in two passes to insure a smooth cut. The first pass went to a depth of 0.075 in. and the second brought the notch to its final dimension of 0.080-in. depth. The notch contour was checked on a profilometer.

Transition curves were established by testing four specimens at each of six temperatures and making the following three measurements on each specimen:

* With the exception of the as-rolled plate which was not heat treated at 800°, and the unstrained A-201 mill-normalized plate, which was not heat treated.

1. Total energy absorbed in breaking specimen
2. Per cent cleavage in the fracture surface
3. Per cent lateral contraction $^1/_{32}$ in. below the notch after fracture

Each of these criteria of brittleness was plotted against temperature and the averages at each temperature were joined by straight lines. The transition temperature was then defined as the temperature at which the curve had a value equal to the mean of its maximum and minimum values. The transition temperature obtained from per cent cleavage curves was called T_B and was considered a measure of the tendency to propagate failure; that from per cent contraction curves was called T_N and was considered a measure of the tendency to initiate failure.

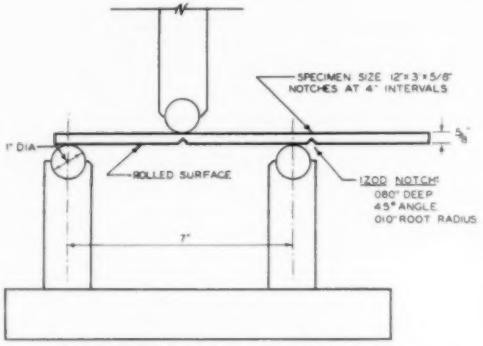


Fig. 2 The Lehigh slow notched-bend test

Slow Notched-Bend Tests

The modified Lehigh bend test (Fig. 2) chosen for this project[1] was also used to construct transition curves for all conditions described under cold forming and heat treatments. The long dimension of the specimen was in the direction of overstrain, and all notches were in the plate surface, perpendicular to the direction of overstrain. The notches were cut with two passes, as for the Charpy specimens.

Autographic load-deflection diagrams were made for every test and the following additional measurements were made on every specimen: (1) per cent cleavage in the fracture surface, and (2) per cent lateral contraction $^1/_{32}$ in. below the notch.

Transition curves and transition temperatures were established in the same way as described above for Charpy results. The first of these measurements (per cent cleavage) determines the transition temperature, T_B, and the second (per cent lateral contraction) determines T_N.

Time Interval Before Testing

In order to eliminate differences due to aging effects, all testing was done to a strict time schedule. Tensile specimens were tested 5 days after the final cold forming or heat treatment; Lehigh bend specimens were tested 7 days after the final treatment; and Charpy specimens were tested 10 days after treatment.

All specimens were machined after the last preparatory treatment.

RESULTS

Tensile-Test Results

All tensile results are summarized in Tables 3–6. Each figure in the tables is the average of values obtained with duplicate test pieces.

Per cent elongation was measured on a 2-in. gage length. If

A_o = initial cross-sectional area
A_b = cross-sectional area at breaking
A_m = cross-sectional area at maximum load

$$\% \text{ R. A. (Reduction of Area)} = \frac{A_o - A_b}{A_o} \times 100$$

$$\epsilon_b \text{ (total ductility)} = \ln \frac{A_o}{A_b}$$

$$\epsilon_u \text{ (uniform ductility)} = \ln \frac{A_o}{A_m}$$

$$\epsilon_n \text{ (necking ductility)} = \ln \frac{A_m}{A_b}$$

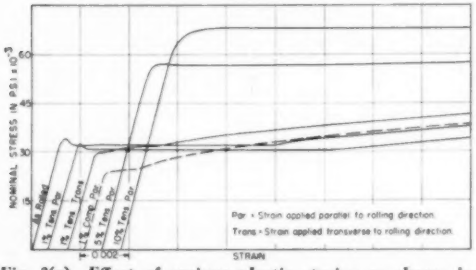


Fig. 3(a) Effect of various plastic strains as shown by typical nominal stress-strain curves from 0.505-in. tension tests

Specimens oriented parallel to direction of rolling. A-201, 1¹/₈-in. material

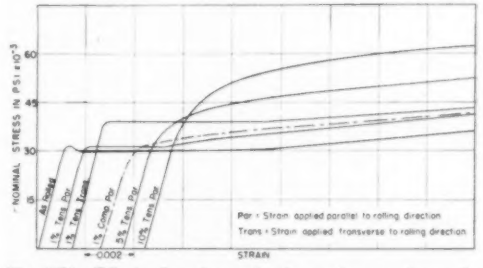


Fig. 3(b) Effect of various plastic strains as shown by typical nominal stress-strain curves from 0.505-in. tension tests

Specimens oriented transverse to direction of rolling. A-201, 1¹/₈-in. material

Table 3—Tensile Properties of A-70, 1¹/₄-In. Material

Prestrain	Test Direction	Postheat °F	% Elong.	% R.A.	ϵ_b	ϵ_u	ϵ_n	Upper Y.P. p.s.i.	Lower Yield Strength p.s.i.	True Br. Str. p.s.i.	Nom. Max. p.s.i.
None	Par. R.D.	None	39.1	59.4	.909	.182	.727	29,300	26,250	115,600	59,000
"	"	500	39.0	58.3	.873	.214	.659	32,050	28,450	112,850	59,900
"	"	1150	37.8	61.2	.948	.228	.720	31,500	28,600	120,700	59,700
"	"	1600	40.5	62.9	.989	.226	.763	45,500	37,350	124,750	62,100
1% Tens.par.R.D.	"	None	40.3	58.1	.868	.198	.670	37,250	36,650	113,650	62,000
"	"	500	39.8	58.0	.865	.195	.670	44,150	41,950	131,150	70,050
"	"	800	34.0	57.9	.864	.209	.655	41,100	39,000	115,200	62,550
"	"	1150	42.0	57.8	.860	.206	.654	35,500	33,000	112,050	61,350
"	"	1600	41.8	64.9	1.050	.204	.846	40,250	36,250	122,600	59,400
5% Tens.par.R.D.	"	None	28.5	58.7	.884	.143	.741	57,250	56,300	115,500	63,350
"	"	500	27.5	59.5	.907	.174	.733	57,800	56,600	130,700	65,800
"	"	800	27.5	54.2	.773	.128	.645	56,550	55,450	114,500	68,450
"	"	1150	36.8	55.0	.829	.184	.645	41,500	37,300	115,700	64,000
"	"	1600	42.3	65.1	1.052	.215	.837	39,050	34,500	119,300	57,750
10% Tens.par.R.D.	"	None	15.3	55.5	.812	.181	.631	67,550	66,150	115,200	67,900
"	"	500	24.5	52.2	.737	.095	.642	65,950	65,350	117,000	71,650
"	"	800	25.3	51.3	.730	.052	.678	58,000	57,050	117,250	72,500
"	"	1150	34.3	56.7	.837	.164	.673	44,000	41,350	118,700	65,750
"	"	1600	42.8	63.8	1.016	.207	.809	41,750	34,850	115,600	58,050
1% Comp.par.R.D.	"	None	36.9	59.4	.891	.183	.708	- **	25,650	116,400	61,650
"	"	500	37.3	57.3	.852	.204	.648	30,300	29,200	113,000	61,950
"	"	800	36.5	57.6	.861	.178	.683	36,000	32,800	114,400	62,500
"	"	1150	39.3	58.8	.892	.219	.673	33,800	31,400	118,450	61,300
"	"	1600	37.8	62.7	.986	.214	.772	42,700	39,050	127,150	63,550
1% Tens.Trans.R.D.	"	None	36.5	59.6	.905	.200	.705	25,600*	24,700	116,000	62,400
"	"	500	36.0	57.7	.859	.198	.661	32,650	31,700	119,150	62,550
"	"	800	34.3	54.9	.796	.207	.589	36,350	33,200	109,000	62,450
"	"	1150	37.5	58.2	.875	.186	.689	32,900	30,600	115,250	61,650
"	"	1600	36.8	62.2	.973	.204	.769	42,950	39,250	127,100	63,800
None	Trans.R.D.	None	32.4	55.0	.799	.202	.597	30,000	26,200	107,350	59,600
"	"	500	34.8	58.8	.887	.217	.670	32,550	29,100	119,200	60,100
"	"	1150	34.8	57.7	.859	.225	.634	32,050	29,350	113,700	59,800
"	"	1600	36.0	60.3	.921	.215	.706	45,300	38,550	123,650	62,400
1% Tens.par.R.D.	"	None	34.0	52.2	.740	.182	.558	26,575*	-	114,150	61,750
"	"	500	35.0	56.5	.832	.204	.628	34,085*	33,250	128,050	68,850
"	"	800	35.5	57.4	.796	.172	.624	33,450	32,750	111,300	62,750
"	"	1150	38.3	57.7	.859	.210	.649	34,600	30,900	108,300	59,200
"	"	1600	39.3	59.1	.893	.214	.679	38,400	37,950	113,350	61,450
5% Tens.par.R.D.	"	None	29.0	53.9	.775	.121	.654	37,900*	-	105,800	62,500
"	"	500	27.3	55.3	.804	.157	.647	- **	38,450	114,500	63,850
"	"	800	27.0	51.9	.730	.136	.594	42,700	41,550	96,950	66,450
"	"	1150	33.3	52.7	.768	.170	.598	39,900	37,950	115,500	60,050
"	"	1600	41.0	59.0	.892	.171	.721	41,400	36,600	110,600	59,450
10% Tens.par.R.D.	"	None	19.3	54.1	.779	.116	.663	-	-	111,600	67,750
"	"	500	20.3	50.4	.700	.067	.633	46,875*	-	109,400	69,550
"	"	800	20.3	49.5	.682	.103	.579	- **	47,100	112,200	71,550
"	"	1150	31.3	57.0	.844	.166	.678	42,400	40,700	116,200	63,300
"	"	1600	38.5	60.6	.932	.206	.726	40,350	36,000	120,800	60,100
1% Comp.par.R.D.	"	None	33.8	57.3	.850	.186	.664	- **	31,850	116,850	61,550
"	"	500	33.8	54.3	.784	.199	.585	36,000	35,000	108,900	62,200
"	"	800	32.5	52.6	.753	.170	.583	39,150	37,000	108,950	63,250
"	"	1150	36.0	56.5	.835	.209	.626	35,100	32,200	110,200	61,100
"	"	1600	37.0	57.3	.852	.225	.627	43,550	39,250	117,700	64,050
1% Tens.Trans.R.D.	"	None	34.0	55.3	.790	.171	.619	37,450	36,200	109,850	61,200
"	"	500	37.5	55.2	.813	.174	.639	38,850	37,450	113,850	62,550
"	"	800	34.3	53.2	.762	.198	.564	40,250	37,500	107,900	62,700
"	"	1150	39.8	57.5	.857	.183	.674	34,750	31,600	113,450	61,700
"	"	1600	37.5	60.5	.930	.205	.725	43,000	38,500	125,500	62,750

Par. R. D. means parallel to rolling direction. Trans. R. D., transverse to rolling direction.

* Yield strength (0.1% offset); no yield point.

** When no upper yield point is reported, the lower yield strength is the stress in the horizontal part of the stress-strain curve. This would also be the stress at a 0.1% offset.

Table 4—Tensile Properties of A-70, 5/8-In. Material

Prestrain	Test Direction	Postheat °F	% Elong.	% R.A.	ϵ_b	ϵ_u	ϵ_n	Upper Y.P. p.s.i.	Lower Yield Strength p.s.i.	True Br. Str. p.s.i.	Nom. Max. p.s.i.
None	Par. R.D.	None	38.5	59.2	.898	.209	.689	37,800	33,900	118,000	64,200
5% Par. R.D.	"	None	28.5	59.3	.944	.180	.764	57,050	56,550	121,950	65,150
"	"	500	29.5	61.6	.958	.143	.315	58,900	56,000	132,900	67,400
"	"	800	28.8	56.6	.834	.155	.679	56,850	51,550	122,100	70,200
"	"	1150	35.5	62.1	.970	.175	.795	43,450	40,700	128,550	65,200
"	"	1600	42.8	69.6	1.189	.234	.955	39,950	36,950	132,150	58,500
None	Trans. R.D.	None	35.5	57.6	.861	.248	.613	37,800	34,000	126,350	65,000
5% Par. R.D.	"	None	26.8	56.5	.882	.109	.773	42,650*	-	124,200	64,800
"	"	500	26.5	51.5	.723	.167	.556	46,800	45,050	115,700	69,000
"	"	800	27.2	51.5	.723	.135	.588	51,400	47,750	117,050	70,650
"	"	1150	32.0	52.3	.742	.235	.507	42,250	40,300	112,450	65,500
"	"	1600	37.8	62.1	.974	.242	.732	40,900	38,450	125,100	60,700

Par. R.D. means parallel to rolling direction. Trans. R.D., transverse to rolling direction.
* Yield Strength (0.1% offset); no yield point.
** When no upper yield point is reported, the lower yield strength is the stress in the horizontal part of the stress-strain curve. This would also be the stress at a 0.1% offset.

$$\text{Nominal yield point} = \frac{\text{Yield load}}{A_o}$$

$$\text{Nominal maximum stress} = \frac{\text{Maximum load}}{A_o}$$

$$\text{True breaking stress} = \frac{\text{Breaking load}}{A_b}$$

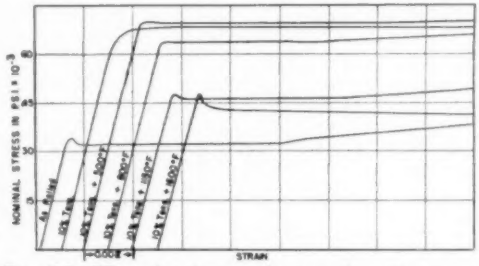


Fig. 4(a) Effect of various postheats as shown by typical nominal stress-strain curves from 0.505-in. tension tests

Specimens oriented parallel to direction of prestrain. A-201, 1¼-in. material

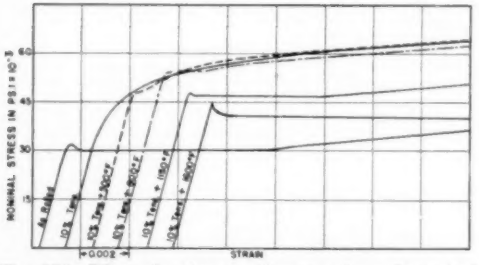


Fig. 4(b) Effect of various postheats as shown by typical nominal stress-strain curves from 0.505-in. tension tests

Specimens oriented perpendicular to direction of prestrain. A-201, 1¼-in. material

Typical autographic nominal stress-strain curves are shown in Figs. 3 (*a*), 3 (*b*), 4 (*a*), 4 (*b*) and 4 (*c*). These are tracings of actual curves.

True stress vs. natural strain curves are shown in Figs. 5 and 6.

Charpy Results

Transition temperatures determined as described under test procedures are listed in Table 7. Typical Charpy transition curves showing the effect of cold work

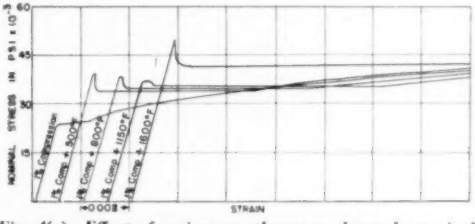


Fig. 4(c) Effect of various postheats as shown by typical nominal stress-strain curves from 0.505-in. tension tests

Specimens oriented parallel to direction of prestrain. A-201, 1¼-in. material

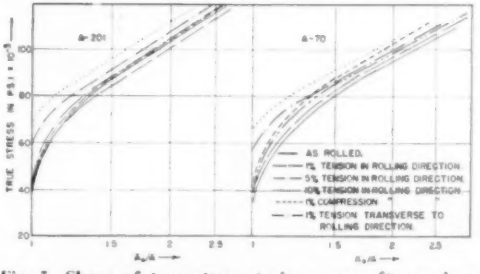


Fig. 5 Shape of true stress-strain curves after various cold deformations

Specimens oriented parallel to the rolling direction

Table 5—Tensile Properties of A-201, 1¼-In. Material

Prestrain	Test Direction	Postheat σ_P	% Elong.	% R.A.	ϵ_b	ϵ_u	ϵ_n	Upper Y.P. p.s.i.	Lower Yield Strength p.s.i.	True Br. Str. p.s.i.	Nom. Max. p.s.i.
None	Par. R.D.	None	40.0	62.7	1.077	.233	.844	33,000	31,600	126,600	63,300
"	"	500	40.3	64.2	1.028	.206	.822	31,800	29,850	127,000	61,450
"	"	1150	36.8	63.0	.991	.180	.811	36,100	32,450	123,250	61,300
"	"	1600	39.8	67.8	1.132	.199	.933	43,600	39,150	139,650	63,950
1% Tens. Par. R.D.	"	None	38.3	65.1	1.074	.239	.835	33,800	31,500	124,950	59,300
"	"	500	40.5	63.8	1.016	.186	.830	39,900	38,600	119,300	61,000
"	"	800	37.0	63.9	1.021	.192	.829	42,850	40,500	123,800	62,150
"	"	1150	38.3	65.7	1.062	.208	.854	40,100	35,900	126,800	60,500
"	"	1600	41.7	70.0	1.203	.195	1.008	- **	32,950	136,500	58,400
5% Tens. Par. R.D.	"	None	29.0	63.6	1.012	.142	.870	58,800	57,950	129,750	65,750
"	"	500	27.8	62.2	.975	.137	.838	58,250	57,650	126,750	67,200
"	"	800	33.0	60.6	.929	.129	.800	56,650	55,800	122,400	66,350
"	"	1150	34.3	62.4	.978	.151	.827	49,400	44,000	123,500	64,500
"	"	1600	42.5	69.7	1.200	.229	.971	40,000	36,850	134,250	60,350
10% Tens. Par. R.D.	"	None	22.6	56.9	.842	.087	.755	69,300	68,600	122,200	71,650
"	"	500	23.3	54.9	.795	.090	.705	70,100	69,300	121,050	75,350
"	"	800	24.8	54.1	.777	.130	.647	64,000	63,200	121,450	76,300
"	"	1150	32.3	59.7	.900	.156	.744	49,600	46,800	129,600	67,175
"	"	1600	40.5	68.1	1.141	.200	.941	42,700	41,000	139,100	63,950
1% Comp. Par. R.D.	"	None	38.0	62.1	.975	.205	.768	24,650	24,650	120,200	62,250
"	"	500	36.3	64.5	1.034	.179	.855	40,100	34,350	126,200	61,900
"	"	800	38.5	62.9	.990	.197	.793	39,600	34,700	121,900	62,100
"	"	1150	38.0	64.1	1.041	.183	.858	36,450	35,050	123,700	60,950
"	"	1600	40.5	69.9	1.196	.233	.963	49,450	41,050	140,550	63,400
1% Tens. Trans. R.D.	"	None	36.5	64.0	1.020	.180	.840	- **	31,250	126,600	62,550
"	"	500	36.0	64.9	1.049	.210	.839	34,100	32,450	129,800	62,700
"	"	800	35.5	63.9	1.019	.191	.828	41,050	35,000	129,400	63,100
"	"	1150	38.3	65.3	1.057	.168	.889	40,600	37,350	132,250	63,150
"	"	1600	39.3	69.5	1.186	.209	.977	47,450	40,700	143,900	64,050
None	Trans. R.D.	None	36.3	57.7	.890	.170	.720	33,250	30,250	115,100	63,200
"	"	500	37.0	54.1	.779	.175	.604	33,750	30,250	109,550	61,750
"	"	1150	35.5	54.0	.778	.190	.588	36,300	32,550	109,500	61,550
"	"	1600	36.8	56.7	.815	.212	.603	42,600	39,350	116,250	63,400
1% Tens. Par. R.D.	"	None	37.3	56.7	.815	.197	.618	31,000	30,750	110,750	60,450
"	"	500	35.0	57.1	.846	.190	.656	37,600	34,650	111,400	60,650
"	"	800	35.5	58.9	.890	.192	.698	39,950	35,500	117,250	60,700
"	"	1150	36.5	58.6	.882	.240	.642	38,850	34,350	117,900	59,700
"	"	1600	40.3	62.5	.983	.188	.795	37,150	36,300	128,200	60,800
5% Tens. Par. R.D.	"	None	31.0	55.1	.802	.106	.696	40,650*	-	110,750	63,900
"	"	500	26.5	54.9	.775	.125	.650	42,500*	-	114,550	65,350
"	"	800	28.5	52.0	.732	.130	.602	46,800	45,950	102,000	66,350
"	"	1150	34.0	57.1	.847	.135	.712	43,700	44,200	123,400	62,900
"	"	1600	40.6	61.4	.956	.185	.771	43,750	38,400	120,650	61,250
10% Tens. Par. R.D.	"	None	19.3	49.6	.690	.066	.624	48,400*	-	109,550	70,800
"	"	500	19.3	47.5	.645	.070	.575	51,900*	-	109,650	74,600
"	"	800	20.8	47.9	.653	.089	.564	54,500*	-	114,000	74,700
"	"	1150	27.3	50.4	.699	.124	.575	49,900	47,350	106,500	67,050
"	"	1600	37.8	56.7	.836	.196	.640	47,400	40,650	117,850	63,250
1% Comp. Par. R.D.	"	None	32.0	56.1	.814	.185	.629	33,000*	-	113,100	61,900
"	"	500	31.5	56.3	.828	.184	.644	38,900	36,000	105,800	62,300
"	"	800	31.5	56.8	.841	.161	.680	42,050	37,300	114,900	62,250
"	"	1150	35.8	56.6	.834	.196	.638	38,200	35,350	111,950	61,150
"	"	1600	35.5	61.8	.960	.235	.725	48,650	39,300	122,250	61,800
1% Tens. Trans. R.D.	"	None	34.8	53.6	.780	.162	.618	39,550	38,700	112,000	63,250
"	"	500	31.5	56.5	.810	.122	.688	39,950	38,700	115,850	62,700
"	"	800	33.0	56.2	.831	.170	.661	39,600	39,100	117,200	63,100
"	"	1150	34.5	53.5	.767	.165	.602	37,500	36,600	111,650	63,450
"	"	1600	36.3	62.0	.967	.189	.778	45,200	40,950	129,700	63,550
			A-201 MILL-NORMALIZED MATERIAL								
None	Par. R.D.	None	41.0	67.1	1.114	.208	.906	37,850	35,100	128,450	60,800
1% Tens. Par. R.D.	"	None	38.5	66.5	1.095	.195	.900	- **	35,800	130,550	62,000
"	"	500	39.3	62.5	1.051	.193	.858	- **	36,150	127,000	62,625
"	"	800	36.2	65.8	1.076	.199	.877	43,975	40,100	131,800	63,150
"	"	1150	40.0	64.9	1.055	.222	.833	42,000	38,000	126,850	61,850
"	"	1600	44.0	67.9	1.137	.190	.947	- **	38,100	134,000	62,600
None	Trans. R.D.	None	39.5	62.5	.979	.224	.755	41,850	35,200	120,800	60,300
1% Tens. Par. R.D.	"	None	40.0	63.6	.979	.191	.788	30,900*	-	121,500	60,000
"	"	500	35.3	59.2	.911	.211	.700	32,000*	-	119,700	61,550
"	"	800	40.3	61.8	.965	.203	.762	42,700	39,500	119,800	60,950
"	"	1150	39.0	63.2	.989	.241	.748	40,950	37,350	121,900	59,200
"	"	1600	37.0	58.7	.947	.187	.760	36,450	36,050	124,050	61,600

Par. R.D. means parallel to rolling direction. Trans. R.D., transverse to rolling direction.

* Yield strength (0.1% offset); no yield point.

** When no upper yield point is reported, the lower yield strength is the stress in the horizontal part of the stress-strain curve. This would also be the stress at a 0.1% offset.

Table 6—Tensile Properties of A-201, 3/8-In. Material

Prestrain	Test Direction	Postheat °F	% Elong.	% R.A.	ϵ_b	ϵ_u	ϵ_n	Upper Y.P. p.s.i.	Lower Yield Strength p.s.i.	True Br. Str. p.s.i.	Nom. Max. p.s.i.
None	Par. R.D.	None	38.0	65.5	1.062	.213	.849	37,200	35,500	131,750	63,150
5% Par.R.D.	"	None	25.5	57.6	.853	.142	.711	44,250*	-	128,700	71,200
"	"	500	28.3	62.0	.970	.141	.829	- **	56,800	133,250	71,100
"	"	800	30.9	61.7	.960	.149	.811	- **	55,600	132,600	71,100
"	"	1150	34.5	63.9	1.056	.200	.856	45,500	43,450	134,050	65,850
"	"	1600	38.3	68.3	1.149	.220	.929	42,650	40,000	142,550	64,800
None	Trans.R.D.	None	37.0	57.8	.865	.201	.664	39,250	36,150	119,250	62,700
5% Par.R.D.	"	None	27.5	56.5	.831	.137	.694	44,450*	-	118,900	66,650
"	"	500	26.5	55.6	.812	.146	.666	- **	48,350	121,150	69,050
"	"	800	27.9	55.2	.803	.130	.673	53,450	49,550	122,800	69,550
"	"	1150	32.5	57.3	.850	.211	.640	46,200	43,100	119,950	64,350
"	"	1600	37.8	61.9	.964	.254	.710	44,750	40,250	131,650	64,700

Par. R.D. means parallel to rolling direction. Trans. R.D., transverse to rolling direction.

* Yield strength (0.1% offset); no yield point.

** When no upper yield point is reported, the lower yield strength is the stress in the horizontal part of the stress-strain curve. This would also be the stress at a 0.1% offset.

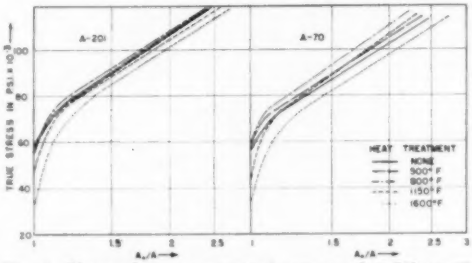


Fig. 6 Shape of true stress-strain curves after 5% tensile strain in rolling direction and various heat treatments

Specimens oriented parallel to direction of prestrain

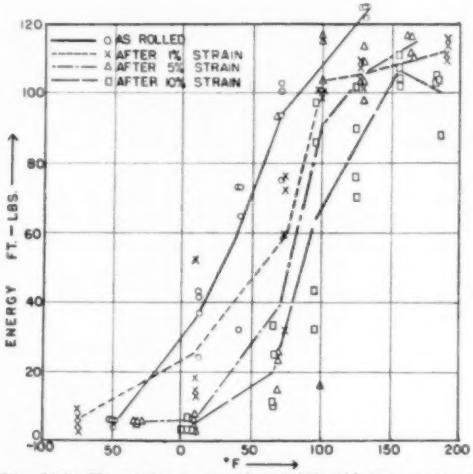


Fig. 7(a) Transition curves for A-201, 1 1/4-in., material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

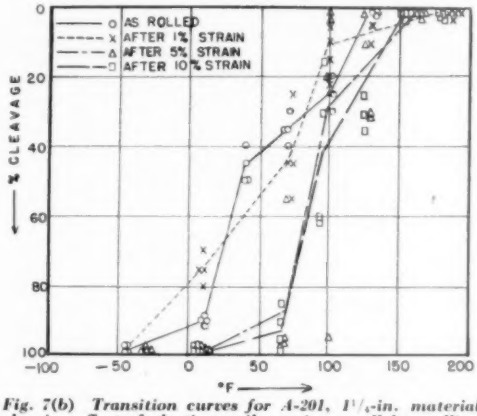


Fig. 7(b) Transition curves for A-201, 1 1/4-in. material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Per cent cleavage

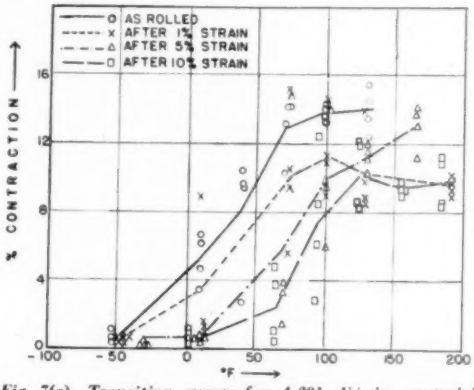


Fig. 7(c) Transition curves for A-201, 1 1/4-in. material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Per cent contraction below notch

Table 7—V-Notch Charpy Transition Temperatures (°F) According to Three Criteria

	Specimen Orientation	A-70, 1¼" Energy	A-70, 1¼" ½ Cleav. T_B	A-70, 1¼" ½ Cont. T_N	A-201, 1¼" Energy	A-201, 1¼" ½ Cleav. T_B	A-201, 1¼" ½ Cont. T_N	A-201 Mill-Normalized, 1¼" Energy	A-201 Mill-Normalized, 1¼" ½ Cleav. T_B	A-201 Mill-Normalized, 1¼" ½ Cont. T_N
As Rec.	Par.R.D.	90	98	83	40	38	30	26	31	14
500°F	"	108	105	77	48	57	44	--	--	--
1150	"	115	119	85	50	58	42	--	--	--
1600	"	69	66	47	-22	-16	-37	--	--	--
1% Tens. par.R.D.	"	153	162	131	68	60	32	25	27	20
500	"	145	135	113	56	66	56	35	42	-4
800	"	149	151	107	61	75	77	48	52	32
1150	"	133	130	103	40	41	30	8	27	-2
1600	"	58	52	50	-9	-8	-13	6	36	-12
5% Tens. par.R.D.	"	156	172	140	78	86	74			
500	"	159	136	122	91	96	80			
800	"	201	192	177	98	110	87			
1150	"	175	161	158	60	66	60			
1600	"	62	56	35	-22	-22	-15			
10% Tens. par. R.D.	"	167	145	115	88	90	80			
500	"	192	182	167	135	142	132			
800	"	191	188	158	109	130	90			
1150	"	166	150	150	77	90	71			
1600	"	72	62	54	-20	-18	-34			
1% Comp. par.R.D.	"	120	125	101	72	80	62			
500	"	117	115	118	46	56	35			
800	"	137	122	115	73	93	82			
1150	"	132	120	110	38	55	25			
1600	"	70	57	57	1	-5	-13			
As Rec.	Trans.R.D.	110	116	96	64	78	50			
1% Tens. Trans.R.D.	"	124	157	95	70	90	78			
500	"	130	156	142	90	94	60			
800	"	137	130	115	82	96	80			
1150	"	131	149	107	72	92	52			
1600	"	82	110	65	8	8	9			
		A-70, 5/8"			A-201, 5/8"					
As Rec.	Par.R.D.	113	145	99	27	75	63			
5% Tens. par.R.D.	"	103	108	98	76	83	90			
500	"	135	158	119	76	84	70			
800	"	173	151	132	80	87	90			
1150	"	133	120	111	51	62	48			
1600	"	56	57	49	-21	-16	-36			

Par. R.D. means parallel to rolling direction. Trans. R.D., transverse to rolling direction.

on the two steels are given in Figs. 7 (*a*), 7 (*b*) and 7 (*c*); and 8 (*a*), 8 (*b*) and 8 (*c*); the effect of heat treatment on Charpy energy curves for as-rolled and cold-worked A-201 material is shown in Figs. 9 (*a*), 9 (*b*), 9 (*c*), 9 (*d*) and 9 (*e*).

Lehigh Slow Notched-Bend Results

Transition temperatures, both T_N and T_B, are listed in Table 8. The effects of cold work are shown by transition curves from Lehigh slow notched-bend tests in Figs. 10 (*a*), 10 (*b*), 11 (*a*) and 11 (*b*); similarly, the effect of heat treatment on the A-201 cold-worked material is shown in Figs. 12 (*a*), 12 (*b*), 12 (*c*), 12 (*d*), 12 (*e*) and 12 (*f*).

DISCUSSION OF RESULTS

Effect of Cold Work on Properties—Tensile Properties

Upper Yield Point and Lower Yield Strength: Numerical values of all upper yield points and lower yield strengths are given in Tables 3–6; the general effect of plastic prestrain on yield characteristics can be seen in Figs. 3 (*a*) and 3 (*b*). When the test direction was parallel to the rolling direction, a relatively sharp knee in the stress-strain curve at yield was almost always maintained, whatever the magnitude of prestrain (Fig. 3 (*a*)). However, when specimens were oriented transverse to the rolling direction, the sharp knee at the yield was wiped out by the larger tensile prestrains (Fig. 3 (*b*)).

A 1% tensile prestrain applied parallel to the rolling direction raised both the upper yield point and lower yield strength in the case of the A-70 material. However, this same strain had practically no effect on the yield characteristics of the A-201 material. The 5 and 10% tensile prestrains in the rolling direction raised the yield points and yield strengths of both materials markedly, as seen in Figs. 3 (*a*) and 3 (*b*). In fact, when tested in the rolling direction, the 10% strain in the rolling direction brought the yield to about 68,000 psi., or only slightly less than the nominal maximum in the same test.

The 1% compressive strain applied in the direction of rolling and the 1% tensile strain applied transverse to the rolling direction had similar effects on the yield characteristics. In both cases the yield points were lowered when tested in the direction of rolling and raised when tested transverse to the rolling direction. The lowering of the tensile yield point after the compressive prestrain illustrates the well-known Bauschinger effect.[3, 4]

Nominal Maximum Stress. With the exception of the 1% prestrains of the A-201 material, all plastic prestrains raised the nominal maximum stress in the tension test (see Tables 3–6). This effect increased with the severity of the prestrain, and amounted to an increase of the order of 8000 psi for specimens prestrained 10%.

The strength increase was of the same order of magnitude with specimens tested both parallel and transverse to the direction of rolling but was usually slightly less in the transverse specimens.

Ductility. Tables 3–6 list five measures of ductility.[5, 6] The most significant of these are probably the uniform ductility (ϵ_u) and the necking ductility (ϵ_n), where ϵ_u is the true strain at maximum load and ϵ_n is the true strain occurring during necking.

Unfortunately, there is experimental difficulty in evaluating ϵ_u and ϵ_n accurately, since this involves measuring the bar diameter at the commencement of necking, i.e., exactly at the maximum load and at the precise spot where necking is beginning. Inaccuracy in measuring is reflected more in the evaluation of ϵ_u, the smaller quantity. Nevertheless, certain conclusions are justified from the tabulated results. In the first place, prestrains seriously lower the available uniform ductility ϵ_u, this effect increasing with the magnitude of the prestrain. ϵ_n also tends to decrease with prestrain. So, therefore, does ϵ_b, the total ducility, which is the sum of ϵ_u and ϵ_n. The per cent reduction of area and per cent elongation also follow the general trends of ϵ_u.

True Stress-Strain Curves. The effect of cold work on the shape of the true stress-strain curves can be seen in

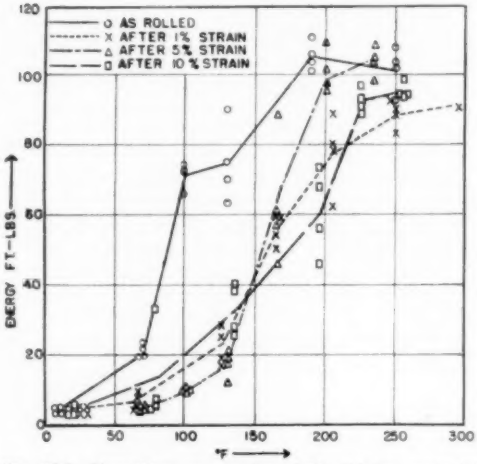


Fig. 8(a) Transition curves for A-70, 1¼-in. material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

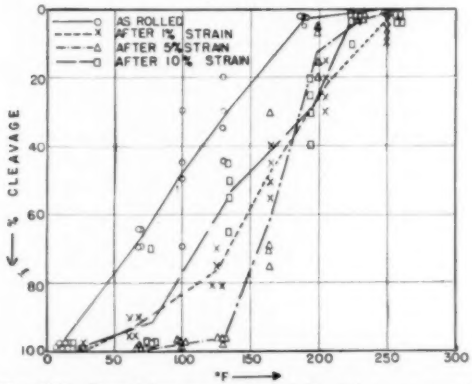


Fig. 8(b) Transition curves for A-70, 1¼-in. material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Per cent cleavage

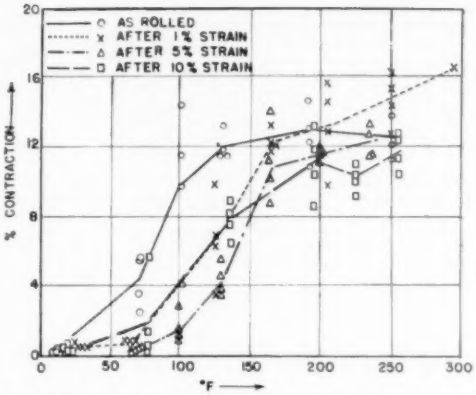


Fig. 8(c) Transition curves for A-70, 1¼-in. material showing effect of plastic tensile strains parallel to rolling direction

Charpy impact test, V-notch. Criterion: Per cent contraction

Table 8—Lehigh Slow Notched-Bend Test Transition Temperatures (°F.) According to Two Criteria

Specimen Orientation	A-70, 1¼" % Cleav. T_B	A-70, 1¼" % Cont. T_N	A-201, 1¼" % Cleav. T_B	A-201, 1¼" % Cont. T_N	A-201, 1¼" Mill-Normalized % Cleav. T_B	A-201, 1¼" Mill-Normalized % Cont. T_N
As Rec. Par.R.D.	163	-42	90	-73	17	-84
500°F "	148	- 9	101	-52	--	--
1150 "	149	-15	88	-43	--	--
1600 "	51	-60	-34	-98	--	--
1% Tens. par.R.D. "	---	-32	92	-46	3	-75
500 "	192	4	95	-60	13	-81
800 "	177	15	97	-35	23	-32
1150 "	163	3	88	-25	6	-79
1600 "	24	-68	-39	<-120	-12	<-120
5% Tens. par.R.D. "	162	48	93	-35		
500 "	190	7	93	-25		
800 "	210	82	109	- 8		
1150 "	178	- 1	93	-40		
1600 "	44	-69	-52	-113		
10% Tens. par.R.D. "	177	48	94	8		
500 "	190	72	103	42		
800 "	211	83	150	65		
1150 "	206	46	126	13		
1600 "	37	-52	-47	-88		
1% Comp. par.R.D. "	152	1	88	-28		
500 "	142	40	92	0		
800 "	115	- 1	90	-30		
1150 "	135	12	59	-73		
1600 "	38	-40	-29	-105		
As Rec. Trans. R.D.	148	-30	25	-19		
1% Tens. Trans.R.D. "	135	-13	50	-18		
500 "	160	-12	51	-13		
800 "	138	7	66	25		
1150 "	135	-27	49	-37		
1600 "	67	-48	17	-50		
	A-70, 5/8"		A-201, 5/8"			
As Rec. Par.R.D.	110	-13	65	-35		
5% Tens. par.R.D. "	118	8	80	-45		
500 "	149	18	83	-16		
800 "	157	13	106	23		
1150 "	128	3	79	-26		
1600 "	42	-56	-43	-122		

Par. R. D. means parallel to rolling direction. Trans. R.D., transverse to rolling direction.

Fig. 5. Varying directions or amounts of prestrains do not change the minimum rate of strain hardening appreciably; i.e., the linear sections of all curves are approximately parallel.

If the curves for prestrained material were shifted to the right a distance representing the degree of prestrain, all the curves should be coincident. Discrepancies must be due to normal within-heat variation from the center to edge of an ingot.[2]

Effects of Orientation. Two orientation relationships were involved in these tests; first, the orientation of the test specimen to the rolling direction, and second, the orientation of the test specimen to the prestrain direction.

When the first relationship is considered, it is seen that specimens oriented parallel to the rolling direction have greater ductility, as evidenced by per cent elongation, per cent reduction of area, ϵ_b, ϵ_R and ϵ_n, than do specimens oriented transverse to the rolling direction, regardless of the magnitude and direction of prestrain.

Yield strengths of unstrained material were practically the same tested in either direction, but after a 1, 5 or 10% tensile strain applied in the rolling direction, the yield strengths were higher when tested in the rolling direction than when tested transverse to the rolling direction, especially in the case of the 5 and 10% tensile strains. The opposite effect was achieved by both the 1% compressive strain applied in the direction of rolling and the 1% tensile strain applied transverse to the rolling direction. Since a compressive strain in one direction produces a tensile strain in the transverse direction, these strains each resulted in a higher yield point when tested transverse to the rolling direction than when tested parallel to the rolling direction.

The true breaking stress was consistently lower for specimens tested transverse to the rolling direction than for those tested parallel. Nominal maximum stress was very little affected by difference in orientation to the rolling direction.

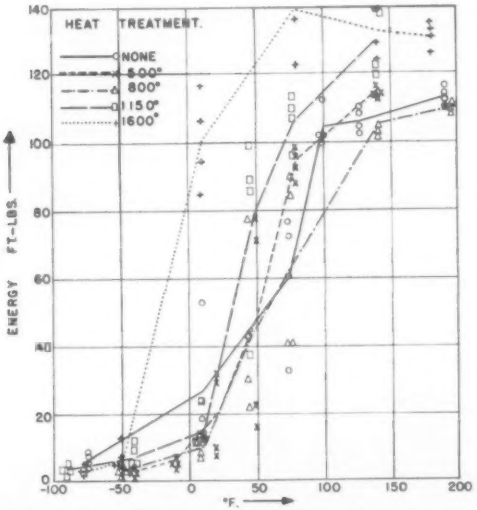


Fig. 9(a) Transition curves for A-201, 1¼-in. material, showing effect of postheats after 1% plastic tensile strain

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

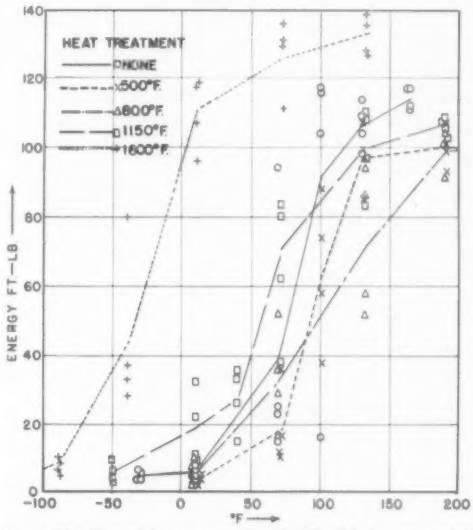


Fig. 9(b) Transition curves for A-201, 1¼-in. material, showing effect of postheats after 5% plastic tensile strain

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

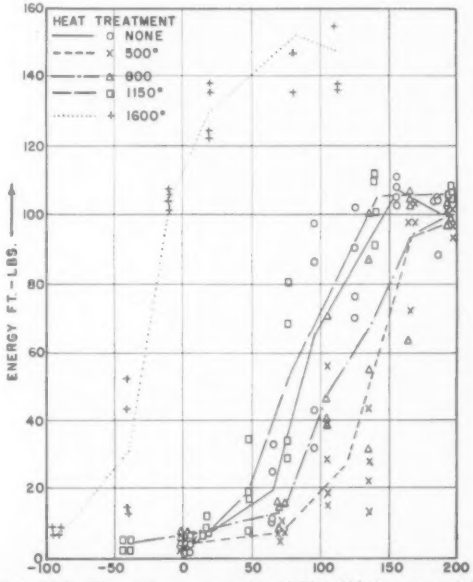


Fig. 9(c) Transition curves for A-201, 1¼-in. material showing effects of postheats after 10% plastic tensile strain

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

Effect of Plate Thickness. In comparing the tensile properties of the $^5/_8$-in. plate (Tables 4 and 6) with those of the $1^1/_4$-in. plate (Tables 3 and 5), it can be seen that in the as-rolled condition the thinner plate resulted in yield values from 5000 to 8000 psi. higher than those of the thicker plate. The $^5/_8$-in. material also had higher true breaking stresses and nominal maximums. However, the ductility (per cent elongation, per cent reduction of area, ϵ_b, ϵ_u, ϵ_a) of the $^5/_8$- and $1^1/_4$-in. plate were practically the same.

After a 5% tensile strain had been applied parallel to the rolling direction, the difference between yield values for the two thicknesses was almost eliminated, though the true breaking stress and nominal maximum of the $^5/_8$-in. material remained slightly higher.

Design Stresses. The results demonstrate very clearly the effects of work hardening in raising the yield strength of plate steel. However, if designers were to take advantage of the increased strength available after cold work during fabrication, the following broad features of the results would have to be borne in mind:

1. Small compressive strains cause a marked decrease in the tensile yield stress.

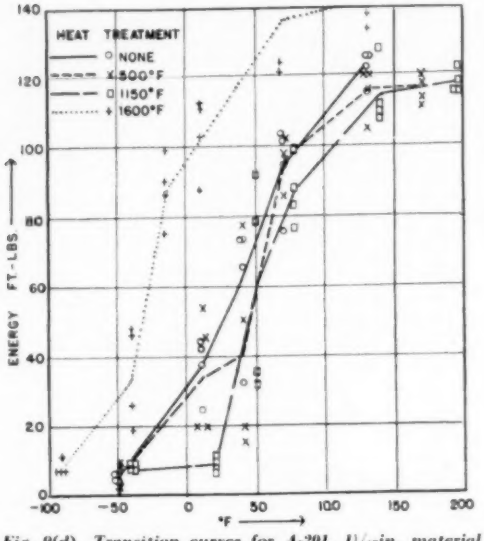


Fig. 9(d) Transition curves for A-201, $1^1/_4$-in. material showing effect of postheats after no plastic tensile strain

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

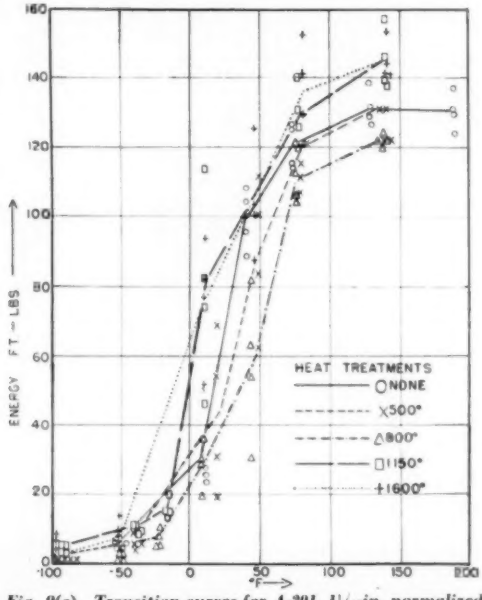


Fig. 9(e) Transition curves for A-201, $1^1/_4$-in. normalized material, showing effect of postheats after 1% plastic tensile strain

Charpy impact test, V-notch. Criterion: Energy ft.-lb.

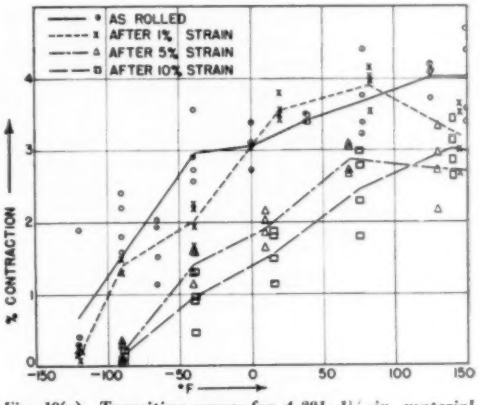


Fig. 10(a) Transition curves for A-201, $1^1/_4$-in. material, showing effect of plastic tensile strains parallel to rolling direction

Lehigh bend test. Criterion: Per cent contraction below notch

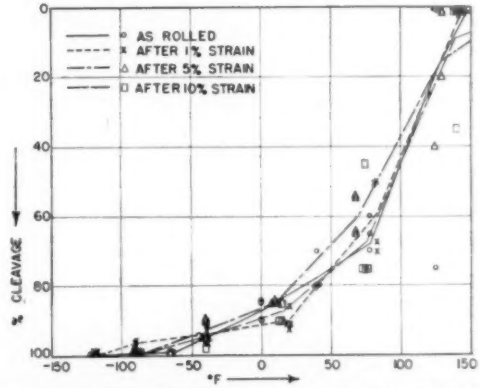


Fig. 10(b) Transition curves for A-201, $1^1/_4$-in. material, showing effect of plastic tensile strains parallel to rolling direction

Lehigh bend test. Criterion: Per cent cleavage

2. For some steels small tensile strains do not raise the yield point appreciably—if at all.
3. The increase in yield stress is much less in a direction transverse to a tensile prestrain than parallel thereto.
4. In the laboratory tests the overstraining was of approximately the same amount throughout the plate, whereas in an actual structure the state of stress and corresponding strain usually vary from point to point.
5. If the design were based on the as-received plate thickness, the increased yield strength as obtained in laboratory tests would be partially offset in an actual structure by the concurrent reduction in plate thickness.

Charpy Results

Figures 7 (*a*), 7 (*b*) and 7 (*c*) show that for the A-201 Al-killed steel, the transition temperature by all three criteria was raised as the plastic tensile strain applied in the direction of rolling was increased. The compressive strain parallel to the rolling direction raised the transition temperature slightly more than did the parallel 1% tensile strain. When the specimen was oriented transverse to the rolling direction, its transition was slightly higher than when oriented parallel. A 1% plastic tensile strain applied parallel to the rolling direction of the normalized A-201 material produced no change in the transition temperature.

For the A-70 rimmed steel, however (Figs. 8 (*a*), 8 (*b*) and 8 (*c*)), the 1, 5 and 10% tensile strains parallel to the rolling direction all had approximately the same effect in raising the transition temperature. In this case the 1% compressive strain in the rolling direction produced lower transition temperatures than the 1% tensile prestrain in the rolling direction. A-70 specimens oriented transverse to the rolling direction had nearly the same level of transition temperature as those oriented parallel to the rolling direction.

An interesting feature of these results, therefore, is the difference between the two steels in response to tensile strains. The transition temperature of the A-201 killed steel was raised only about 20° by the 1% tensile strain, and increasing strains continued to raise the transition temperature, resulting in a total rise of about 50°. The temperature of the A-70 rimmed steel, however, was immediately raised about 60° by the 1% strain, while further straining had little effect.

The A-70 transition values were invariably from 50 to 100° higher than those for the A-201 steel. The transition temperatures for the $^5/_8$-in. material tended to be lower than those for the $1^1/_4$-in. plate, the effect being more noticeable in the case of the A-70 steel.

Lehigh Slow Notched-Bend Results. Figures 10 (*a*) and 10 (*b*) illustrate the effects of plastic tensile strains on A-201 Al-killed steel. As shown by Fig. 10 (*a*), the T_N transition temperatures were consistently raised as the strain was increased, resulting in a total rise of 80° F. On the other hand, Fig. 10 (*b*) indicates that T_B was insensitive to the various tensile strains parallel to the rolling direction. The specimens oriented transverse to the rolling direction had lower T_B and higher T_N values than did those oriented parallel to the rolling direction. A 1% strain in the rolling direction of the normalized plate had very little effect on T_N and T_B.

The A-70 rimmed steel showed a slightly different response to tensile strains parallel to the rolling direction, seen in Figs. 11 (*a*) and 11 (*b*). Here the 1% strain produced practically no change in the value of T_N; the 5% strain raised T_N sharply—about 90° F; and the 10% strain resulted in no further increase. T_B values, taken from the curves in Fig. 11 (*b*), were constant for these strains, except in the case of the 1%, which resulted in an inconsistency that must be more extensively investigated. The 1% compressive strain in the rolling direction (Table 8) had a more pronounced effect on T_N than the 1% tensile strain in the same direction. As with the A-201 material, specimens oriented transverse to the rolling direction had lower T_B and higher T_N values than those oriented parallel to the rolling direction.

Comparing the transition temperatures of the two steels, the values for the A-70 material were invariably from 20 to 80° F. higher than those of the A-201 steel.

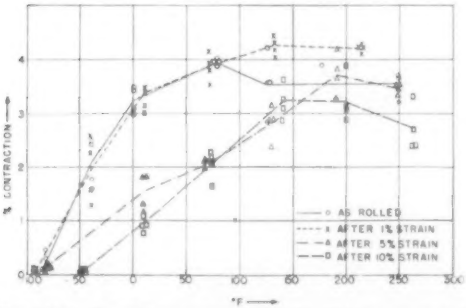


Fig. 11(a) Transition curves for A-70, $1^1/_4$-in. material, showing effect of plastic tensile strains parallel to rolling direction

Lehigh bend test. Criterion: Per cent contraction below notch

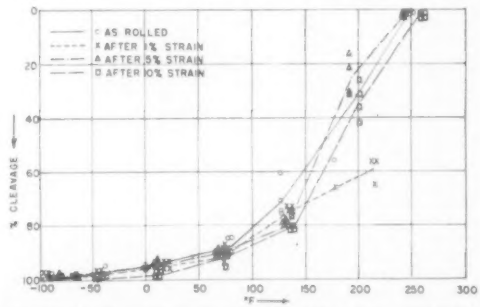


Fig. 11(b) Transition curves for A-70, $1^1/_4$-in. material, showing effect of plastic tensile strains parallel to rolling direction

Lehigh bend test. Criterion: Per cent cleavage

Both steels indicated that a 1% compressive strain in the rolling direction was more effective in raising the T_N value than a 1% tensile strain in the rolling direction. For the $^5/_8$ in. thickness of both steels, T_B values were lower than the $1^1/_4$ in. values.

Effect of Heat Treatment on Properties—Tensile Properties

Yield Point. For as-rolled plate, the yield point was raised considerably by normalizing (see Tables 3 and 5); lower heat treatments produced little change in the yield points.

In the case of prestrained plate the effectiveness of heat treatment in restoring the yield point is shown very clearly in Figs. 4 (*a*), 4 (*b*) and 4 (*c*) for the A-201 material. Considering first the material strained in tension, the results show that postheating at 500° F. almost always restored or raised the yield points; this may be considered a strain-aging effect. The yield-point elevation during aging was much more marked after small deformations than after strains of 5 and 10%; it appeared to be of the same order of magnitude in both the rimmed and Al-killed steels. The 800° F. treatment had an effect on yield points similar to the 500° F. treatment, sometimes giving yield points higher than the latter, sometimes lower. Treatment at 1150° F. usually gave lower yield points than either of the lower temperature treatments and invariably restored yield points removed by cold work. Normalizing the prestrained $1^1/_4$-in. A-70 material at 1600° F. resulted in an upper yield point of about 42,000 psi. regardless of the previous straining history. With A-201 material, however, the yield points of normalized material were higher the greater the degree of prestrain. The 1% compressive strain in the rolling direction and the 1% tensile

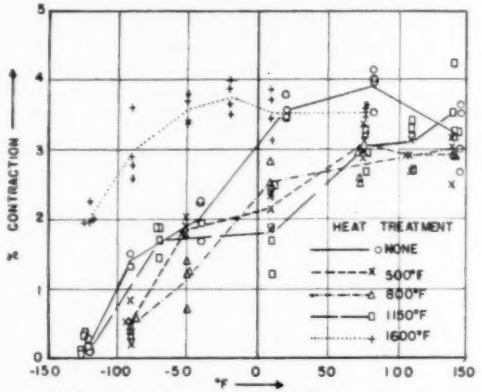


Fig. 12(a) Transition curves for A-201, $1^1/_4$-in. material, after plastic tensile strain of 1% in rolling direction. Various heat treatments

Lehigh bend test. Criterion: Per cent contraction below notch

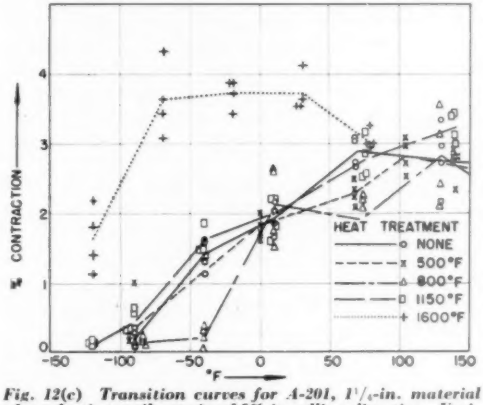


Fig. 12(c) Transition curves for A-201, $1^1/_4$-in. material after plastic tensile strain of 5% in rolling direction. Various heat treatments

Lehigh bend tests. Criterion: Per cent contraction below notch

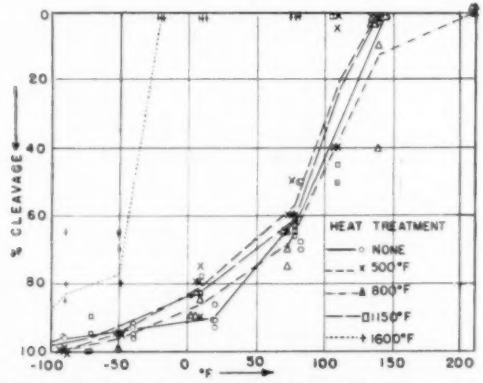


Fig. 12(b) Transition curves for A-201, $1^1/_4$-in. material, after plastic tensile strain of 1% in rolling direction. Various heat treatments

Lehigh bend test. Criterion: Per cent cleavage

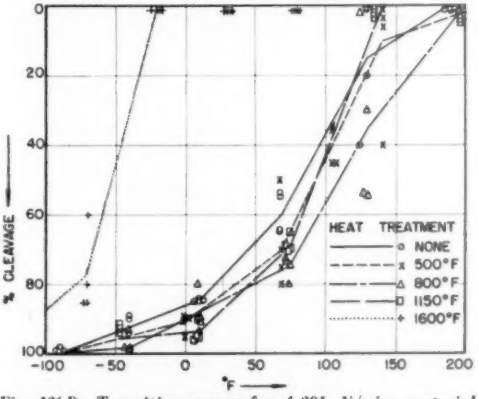


Fig. 12(d) Transition curves for A-201, $1^1/_4$-in. material after plastic tensile strain of 5% in rolling direction. Various heat treatments

Lehigh bend tests. Criterion: Per cent cleavage

strain transverse to the rolling direction both produced a high yield point after normalizing. There is evidence of these effects in the A-70 results also, but the magnitude of the variation is less.

Nominal Maximum Stress. The nominal maximum stress of as-rolled plate of either steel was not affected appreciably by any heat treatment.

The effects of heat treatment on the nominal maximum stress of prestrained plate were generally similar to the effects described above on the yield point. The accelerated aging at 500° F. almost always caused an increase in the nominal maximum stress, this increase being very marked in the case of A-70 material prestrained 1% in tension. Normalizing caused the same variation in nominal maximum stress as in yield point, but again this variation was much less in the A-70 than in the A-201 material.

Ductility. Heat treatment of as-rolled plate resulted in little change in ductility, as can be seen in Tables 3 and 5.

It is difficult to generalize concerning the effects of heat treatment on prestrained plate, but there was a tendency for ductility measurements to be lowest after an 800 or 500° F. treatment, presumably because of strain aging. Full normalizing was the only treatment which invariably increased the total ductility (ϵ_b) and the necking ductility (ϵ_n), and usually improved ϵ_u also.

The total ductility after normalizing was less for higher prestrains, but ϵ_u varied erratically with the straining history.

True Stress-Strain Curves. Figure 6 shows the effects of heat treatment on the shape of the true stress-strain curve after 5% plastic tensile prestrain. Noteworthy features of the curves are the marked strengthening effect of strain aging after heat treatment at 500 and 800° F., and the definite softening effect of normalizing.

Charpy Results

The effects of postheat after plastic strain on Charpy transition temperatures are shown in Figs. 9 (*a*), 9 (*b*) and 9 (*c*), and Table 7. It may be seen that for both steels the only postheat treatment which appreciably lowered the transition temperatures was normalizing at 1600° F. In some cases, particularly after 10% strain, the 500 and 800° F. postheat actually raised the transition temperature. The 1150° F. treatment usually lowered the temperature slightly.

Postheats had very little effect on the normalized A-201 material after straining, as shown in Fig. 9 (*e*).

The heat treatment of unstrained material produced similar effects. Here, as shown in Fig. 9 (*d*), the 500° and even 1150° F. postheat raised the transition temperature slightly, while the 1600° F. normalizing brought the transition below the level of the as-received material.

Lehigh Slow Notched-Bend Results

The effects of various heat treatments on the A-201 material after three tensile strains are shown in Figs. 12 (*a*) to 12 (*f*), and a summary of the effects for both materials after all strains is given in Table 8.

With a few minor exceptions, the 500° F. treatment raised the transition temperature, whether T_N or T_B, and the 800° F. treatment elevated it slightly more. Often, but not consistently, the 1150° F. postheat brought the transition temperature back near the level of the strained unheat-treated material. Invariably the 1600° F. normalizing treatment produced transition temperatures as low as, or lower than, the as-received material.

The normalized A-201 material showed the same general response to the various postheats after straining, but to a lesser degree.

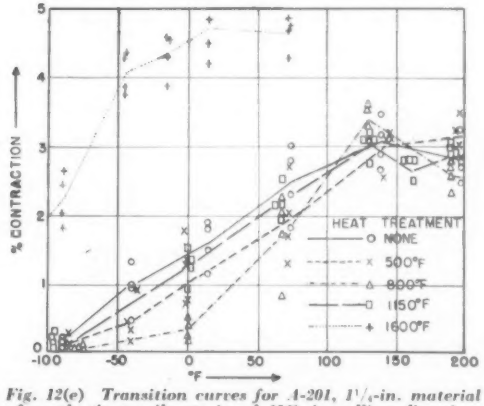


Fig. 12(e) Transition curves for A-201, 1¼-in. material after plastic tensile strain of 10% in rolling direction. Various heat treatments

Lehigh bend test. Criterion: Per cent contraction below notch

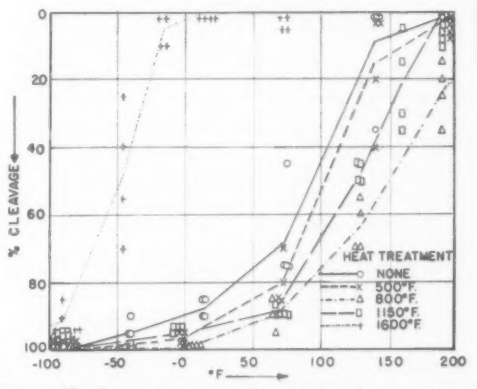


Fig. 12(f) Transition curves for A-201, 1¼-in. material after plastic tensile strain of 10% in rolling direction. Various heat treatments

Lehigh bend test. Criterion: Per cent cleavage

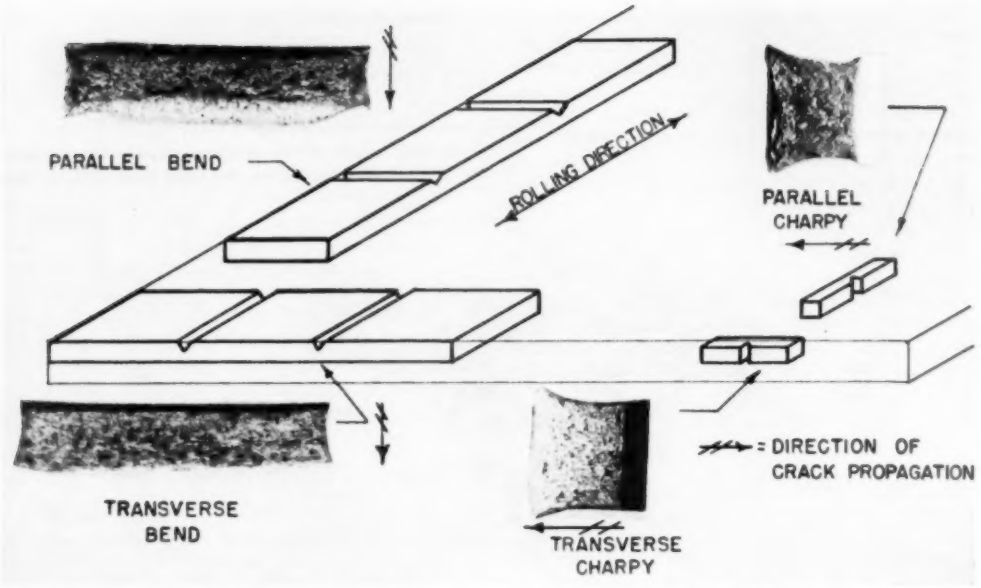


Fig. 13 Fractures of bend and Charpy specimens oriented parallel and transverse to the rolling direction. A-201 material

The level of transition temperatures for the A-70 material was consistently higher than that for the A-201 material, the difference being usually of the order of 70° F. However, the response of the two steels to the various heat treatments was quite similar, neither showing a greater aging tendency than the other.

Consideration of Intermediate Temperature Heat Treatment

Current practice in treating assembled vessels before putting them into service is to heat treat at about 1150° F., but there is some feeling that a lower temperature of the order of 800° F. would be just as satisfactory and more economical. The present results do not support this view. Tables 3–8 show that prestrained materials heat treated at 800° F. invariably exhibited low ductility and high transition temperatures and, in fact, it was frequently found that 800° F. produced the lowest ductility and highest transition temperatures of any heat treatment for the particular prestrain under consideration.

While heat treatment at 1150° F. usually caused an improvement in ductility and transition temperatures compared with lower heat-treatment temperatures, it is evident from the results that nothing short of normalizing would suffice to restore these properties to approximately those of the as-rolled plate.

Comparison of Charpy and Slow Notched-Bend Results

This study, for which transition curves were determined currently by the Charpy impact test and the Lehigh slow notched-bend test, affords an opportunity for comparing the relative behavior of the two tests.

The two tests indicated the same general trends for both steels after cold work and heat treatment. Differences between steels, between degrees of strain and between heat-treating temperatures were shown up by changes in transition temperature of about the same order. However, it is interesting to note some differences in the results of the two tests as conducted in this study:

1. The temperature range for the Charpy transition curves was consistently higher than that for the Lehigh slow notch-bend test curves. It was not possible to complete the lower part of some bend-test curves for normalized materials because an inconveniently low temperature was required.
2. T_B values as determined by the bend test were unchanged by the various degrees of tensile and compressive strain in the rolling direction, though they responded to the heat treatments. Charpy T_B values behaved in the same general way as the T_N values from both tests. This is to be expected from the difference in size and geometry of the two test specimens, which affects the tendency to propagate failure.
3. When bend specimens were oriented transverse to the rolling direction, T_B values were lower than for specimens oriented parallel to the rolling direction, while T_N values were higher. Transverse Charpy bars, however, resulted in T_B

values higher than those for specimens, oriented parallel to the rolling direction. Figure 13 shows fractures of A-201 bend and Charpy specimens cut parallel and transverse to the rolling direction. The various orientations of the direction of crack propagation to the fiber structure, as shown in the figure, might account for the change in T_B and T_N values for different orientations.

These observations lead one to the conclusion that both tests are useful in following the notch-brittleness characteristics of strained and heat-treated steel. The slower speed of testing, larger size and greater constraint of the Lehigh slow notched-bend specimen as compared with the Charpy specimen result in a different emphasis on the tendencies to initiate and propagate failure.

CONCLUSIONS

The following features of the results seem to be the most significant:

1. Tensile strains as small as 1% in the rolling direction or transverse did not affect the tensile properties very seriously. In the case of A-70 material they caused a large rise in T_N transition temperatures; larger tensile prestrains resulted in transition temperatures only slightly higher than those after 1% strain. With A-201 material, T_N was consistently raised by increasing tensile strains.
2. The yield strength and maximum stress in a tensile test increased with increased magnitude of tensile prestrain. Compressive prestrain caused a marked decrease in tensile yield point.
3. The rimmed and the Al-killed steels had similar tendencies to strain age.
4. Normalizing at 1600° F. was the only heat treatment to restore consistently the ductility and transition temperatures of cold-worked plate to their as-rolled levels. Heat treatment at 1150° F. was frequently advantageous but treatment at 500 and 800° F. usually caused these properties to deteriorate still further from their as-strained level.

ACKNOWLEDGMENTS

This project was carried out jointly by the Fritz Engineering Lab. of the Civil Engineering Dept. and by the Metallurgy Dept. of Lehigh University. It was sponsored by the Pressure Vessel Research Committee of the Welding Research Council, which is directed by William Spraragen. Walter Samans is Chairman of the Pressure Vessel Research Committee, Russell J. Love, former Executive Secretary and Boniface E. Rossi, current Executive Secretary. The Fabrication Division of P.V.R.C. gave technical guidance and approval of various stages of the work, under the guidance of Chairman Harry Boardman.

References

1. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., "A Comparison of Notch Tests and Notch-Brittleness Criteria," THE WELDING JOURNAL, **28** (1), Research Suppl., 25-s to 33-s (1949).
2. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., "Composition and Property Variation of Two Steels," *Ibid.*, **28** (5), Research Suppl., 227-s to 235-s (1949).
3. Bauschinger, J., "Changes of the Elastic Limit and the Modulus of Elasticity in Various Metals" (in German), *Zivilingenieur*, **27**, 289–347 (1881).
4. Hollomon, J. H., and Jaffe, L. D., "Ferrous Metallurgical Design," 97–100 (1947).
5. MacGregor, D. W., "The Tension Test," *Proc. A.S.T.M.*, **40**, 508–534 (1940).
6. Johnston, Bruce, and Opila, Francis, "Compression and Tension Tests of Structural Alloys," *Proc. A.S.T.M.*, **41**, 552–570 (1941).

Measurement and Relaxation of Residual Stresses

A comprehensive treatise on residual stresses including methods of measurement, origin, relaxation and control of residual stresses. The influence of residual stresses is briefly discussed

by W. Soete, Ing.

I. INTRODUCTION

THE Institute of Metals organized a Symposium in October 1947 in London devoted to residual stresses. The British experts discussed for two days thirty-six papers divided in the following three sections:

1. The measurement of residual stresses
2. The origin, relaxation and control of residual stresses
3. The influence of residual stresses

The title chosen for this lecture might give the impression that it is proposed to develop the first two points enumerated above. The author feels that he is neither competent nor has he the time to develop this vast subject.

The aim of this lecture is on the one hand to give a brief résumé of an industrial method for the measurement of residual stresses and on the other hand to make certain suggestions and to communicate certain experiments undertaken in preparation of extensive researches into the relaxation of residual stresses.

II. CLASSIFICATION OF RESIDUAL STRESSES

In a branch of inquiry as complex as that concerning residual stresses, it is necessary to agree on a certain terminology. It is necessary to distinguish between residual stresses of different types.

W. Soete is a Professor at the University in Ghent, Belgium, and Scientific Adviser to the Belgian Welding Institute.

Lecture delivered at the meeting of the International Institute of Welding held at Brussels on June 9, 1948. The experimental part of this study was carried out with the collaboration of R. Vancrombrugge, Ing. The translation of this lecture for publication in Great Britain was made by Dr. R. Week of the British Welding Research Association.

(*A*) *Reaction Stresses*

These are residual stresses whose value seems constant or varies only slightly in any direction of the piece. These stresses are characterized by a stress gradient equal to zero or, at any rate, a stress gradient which is rather small. They come into play particularly if pieces are welded under restraint. The measurement of these stresses is relatively simple and the effects of these stresses are known. They do, in fact, behave in the same way as stresses derived from external loads.

(*B*) *Macroscopic Stresses*[2] (*Body Stresses*)

These residual stresses only exist in certain portions of the piece. They are characterized by a considerable stress gradient. These stresses appear, for instance, after plastic deformation (cold work) and in weld seams.

(*C*) *Microscopic Stresses of Structural Stresses*[2]

These stresses are characterized by the fact that they vary from grain to grain. They are practically uncontrollable and have only a relative value for the engineer. The only way these stresses can be taken into account—by an application of the law of great numbers—is by considering them as constituting an intrinsic property of the metal.

It follows from the preceding paragraphs that it is particularly the macroscopic stresses which pose problems for the engineer. In what follows we call these macroscopic stresses residual stresses. The investigation of the effect of stress gradients, which is their principal characteristic, dominates the entire problem of the influence of such stresses.

Unfortunately, information on the effect of stress gradients on the behavior of a piece of metal is very limited. Numerous publications have been devoted to the study of the notch effect. However, the notch does not merely introduce a stress gradient, but also creates

at the same time biaxial or triaxial stresses. The effect of these latter stresses may mask the effect of the gradient. It is also necessary to observe among other things that a notch forms a geometric discontinuity whose influence is not modified after a slight plastic deformation contrary to a mere stress gradient, which is, of course, modified by plastic deformation. It follows from this that, for instance, the comparison from the point of view of fatigue of a gradient produced by a notch and a gradient formed by residual stresses is impossible. A study of a simple gradient may be made by means of bend tests, the height of the test piece permitting a variation of the value of the gradient. In practice, residual stresses have generally a double or triple gradient, that is the value of the gradient varies in two or three principal directions. The investigation of this effect, "multiple concentrations," is a factor which has so far been neglected in the study of metals, despite its great importance. We take advantage of this occasion to express the view that a systematic study of this problem should be undertaken. In my opinion it will form the foundation for any comprehension of the effect of residual stresses on the behavior of a welded structure.

III. MEASUREMENT OF RESIDUAL STRESSES

After having devoted numerous meetings to the problem of "Brittle Fracture" (failure by decohesion), the Belgian Institute of Welding, taking into consideration that the majority of reports considered residual stresses as the cause of all the difficulties encountered in certain welded structures, came to the conclusion that knowledge of their behavior was hardly advanced by incriminating that great unknown "residual stresses" and decided to investigate their measurement.

The first investigation devoted to the examination of the possibilities of measuring residual stresses by X-rays demonstrated the great value of this method for research work and in the laboratory, but concluded that it was impracticable in the workshop.[3,4] In the absence of an industrial method, it was decided to embark on an industrial procedure for the measurement of residual stresses; this research is actually still in progress. Two reports have already been published in *Revue de la Soudure-Lastijdschrift*.[5,6] However, these papers were published in Dutch, and we believe it be to useful to state here briefly the principles of the method. The basic idea of the procedure is that proposed by Mathar in 1933, which consists of drilling a small hole in the structure to be investigated. This hole causes certain elastic recoveries, which were measured by Mathar by means of a mechanical extensometer. The results obtained by Mathar's apparatus were criticized and many investigators have abandoned this procedure. However, by replacing Mathar's extensometer by electric resistance strain gages, one eliminates at once the difficulties of measurement, and, at the same time, the precision is greatly increased. With these ideas as a basis, we have developed a method for industrial application.

The problem has been solved in two stages. The first stage supposes that the state of stress is plane and does not vary with depth; the second stage provides a solution for states of plane stress which vary in depth.

In both cases one starts off by placing three electric resistance strain gages in star form, making angles of 120° with each other (Fig. 1).

(*A*) *Plane Homogeneous State of Stress*

In the case of a state of stress which does not vary with depth, it is sufficient to measure the strains which are relieved by drilling a hole at the center of convergence of the three strain gages, if these strains are designated E_0', E_{+60}' and E_{-60}', the actual strains E_0, E_{+60}, E_{-60} existing at the spot examined are given by the following formulas:

$$E_0 = K_1 E_0' + K_2(E_0' + E_{+60}' + E_{-60}')$$
$$E_{+60} = K_1 E_{+60}' + K_2(E_0' + E_{+60}' + E_{-60}')$$
$$E_{-60} = K_1 E_{-60}' + K_2(E_0' + E_{+60}' + E_{-60}')$$

In these formulas K_1 and K_0 are constants which only depend on the diameter 2a of the hole, the gage length of the strain gages $r_2 - r_1$, and the distance r_1 of the gage from the center of the hole; they are given by these formulas:

$$K_i = \frac{B}{B'} \quad K = \frac{AB' - A'B}{3A'B'}$$

Fig. 1 Resistance strain gages attached in star form for the measurement of residual stresses

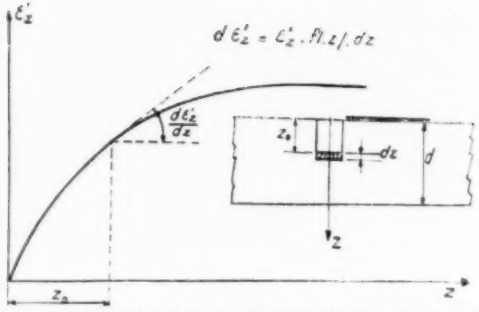


Fig. 2 Principle of the method used for measuring stresses in depth

where:

$A = 0.35$;
$B = 0.65$;

$$A' = -0.65 \times \frac{a^2}{r_1 r_2}$$

$$B' = \frac{2a^2}{r_1 r_2}\left[-1 + 0.325\,\frac{a^2(r_1^2 + r_1 r_2 + r_2^2)}{r_1^2 r_2^2}\right]$$

If the real strains in the three directions of measurement are known, it is easy to deduct from these the state of stress. There exists a very simple graphical method using Mohr's circle.

(*B*) *Plane State of Stress Varying in Depth*

If the state of stress varies in depth it is evident that the procedure outlined above will only give a mean of the stress existing at the point where the strain gages are attached. In this case, instead of measuring the strain after drilling, one records a curve giving the strains relieved during drilling in function of the depth of the hole.

It is easy to show that the strain E_z' relieved at depth z can be expressed in this form (see Fig. 2).

$$E_z' = \frac{dE_z'}{dz}\,\frac{1}{f(z)}$$

In this expression dE'_z/dz is the tangent to the curve at the point z and $f(z)$ is an exponential function which must attain its asymptotic value for a value of z approximately equal to the diameter of the hole.

The determination of $f(z)$ can be carried out experimentally. Theoretically it varies with the thickness of the plate. However, if drills of 6 mm. diameter are used it is probable that, for all thicknesses greater than 10 mm. this function will be practically the same. It is therefore necessary to determine this function $f(z)$ for all thicknesses smaller than 10 mm. This determination is one of the researches which the Belgian Institute of Welding hopes to undertake in the near future.

These preliminary experiments have already provided an idea of the general character of this function $f(z)$ and some measurements of residual stresses in depth have been carried out.

If the Belgian Institute of Welding has partially solved the problem of measuring residual stresses it has, on the other hand, still to take its first steps in the investigation of their influence and their relief.

The preparation of these studies has led us to carry out some isolated experiments which have convinced us that there remains a vast field of research to be explored. In what follows, we take stock of these experiments and of suggestions which have occurred to us. We reiterate that they cannot be considered as points established with any certainty.

IV. POSSIBILITIES OF RELIEVING RESIDUAL STRESSES

(*A*) *Introduction*

After having developed an industrial procedure for measuring residual stresses, the next step should obviously be the investigation of their influence. This subject in itself could form the theme for a Congress; we shall limit ourselves to recall certain statements made by other experimentalists, especially as this part of the subject has been discussed by Dr. Weck.[8] From investigations made in Switzerland,[9] in the United States of America[10] and in Russia,[11] it seems to follow that the influence of residual stresses is less unfavorable than was generally believed; it follows clearly from these experiments that neither the static resistance nor the fatigue resistance are reduced by the residual stresses. On the other hand, their effect on the chemical resistance of the metal has been established.[12,13] We must further add that relief of residual stresses is necessary for all components which are to be machined without being permitted to undergo deformation during machining, which might make the piece useless.

The engineer has actually at his disposal several processes which permit residual stresses to be reduced. We propose to examine these briefly.

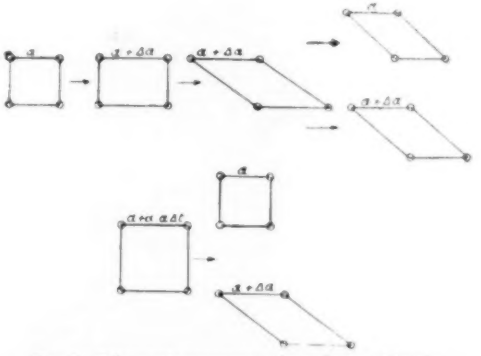


Fig. 3 Schematic representation of crystal lattice

(Above) **Square deformed into rectangle representing elastic deformation. Rectangle deformed into parallelogram giving way to smaller parallelograms representing complete and partial unloading, respectively**

(Below) **Lattice of a metal which cools freely and metal which is constrained during cooling**

(*B*) *Nature of Residual Stresses*

Before describing these procedures, and in order to avoid all confusion, it appears useful to devote a few words to the nature of residual stresses. Let us assume that a piece which is free from all residual stresses is subjected to simple bending. As long as gliding does not occur, the stresses are elastic and produce an increase in the interatomic distance; this distance resumes its normal value when the external forces disappear. We represent these stresses schematically by sketches of simple squares transformed into rectangles (Fig. 3). When the force increases, the mechanism of deformation will change at certain points and plastic gliding will appear, and if the piece is loaded by weight or by pressure, the external force will not be modified by the deformation. That means that the stresses may assume a different distribution, but they will not disappear. We represent this state by a rectangle transformed into a parallelogram (Fig. 3).

If the piece is now unloaded, only the elastic deformations will have a tendency to disappear; this will only be possible if this disappearance can take place over the entire cross section, which means that in the case of a stress gradient, the disappearance can only be partial. In the unloaded piece, elastic deformations will remain and the piece will be the seat of residual stresses. From this preceding consideration, we can draw the conclusion that residual stresses arise from a localized plastic deformation and that it is necessary to distinguish stressed metal under load and stressed metal free from external load. Let us now examine the case of shrinkage stresses in welds which arise from the solidification of the metal. This shrinkage which, when cooling is uniform, takes place in the manner of an elastic process, is hindered in its normal mechanism in view of the presence of the adjacent cold base metal. It follows from this that shrinkage will only be possible by means of a process of gliding, which means that the metal of the weld seam is in the state characterized by the parallelogram.

The fact that measurements of the longitudinal stresses give values of the order of magnitude of the yield limit of the metal deposited confirms this hypothesis.

Metal deposited in a weld seam is therefore metal in a plastic state subject to very severe constraint. If it were possible to isolate this metal from the base metal, at the same time preserving its state of strain and stress, such metal would have a modulus of elasticity $E=0$ and a Poisson's ratio $\nu=1/2$. But this weld seam forms, by its nature, an integral part of the base metal and it would be dangerous to conclude *a priori* that this metal would behave as if it were isolated.

(*C*) *The Relaxation in General*

The relief of residual stresses has as its object the elimination of the elastic deformations; it does not consider the plastic deformations. In principle this can be achieved in two different ways:

1. The first method consists in modifying the properties of the metal, especially to reduce the interatomic forces so that the atoms have the possibility of resuming their normal positions. This is achieved by heating the entire construction to a temperature sufficient for the yield limit of the metal to fall to zero. For steel this occurs by heating the construction for a sufficiently long time to 650° C. This operation is known under the name of "stress relieving heat treatment" and is universally applied.

2. The second method consists in the application of a state of stress of opposite sense to the existing state of stress in such a way that superposition of the two results in residual stresses is very much diminished, zero or even changed in sign. This superposition of a state of compression on an existing state of tension in the weld seam can be achieved (*a*) by means of the base metal or (*b*) directly on the deposited metal.

(*D*) *Superposition of a State of Compression by Action on the Base Metal*

1. General Remarks. Methods using the base metal to superimpose a state of compression on the weld seam achieve this object from (*a*) the shrinkage force of the yielded base metal and (*b*) from the elasticity of the base metal.

In the American literature the first is known under the name of "low temperature stress relieving" and the second under "mechanical stress relieving."

2. *Low-Temperature Stress Relieving.*[14] Description of this process has been made the subject of several publications in the technical press. It is carried out by heating progressively two zones of 15 cm. width at both sides of the weld; the weld itself is maintained at normal temperature either by an air jet or by a water jet. In addition, there are two water sprays placed a few centimeters behind the flames. The apparatus is propelled at a certain speed along the weld seam. The flames, the cooling and speed of travel, are regulated in such a fashion that the maximum temperature never exceeds 200° C. In order to simplify the mechanism of this process it might be supposed that the entire piece is heated to 200 °C. with the exception, however, of the weld seam, which is maintained at normal temperature. Heating to 200° C creates thermal dilatation in a piece of steel free from restraint of the order of magnitude of 2.4×10^{-4}. It is understood that this dilatation will be partially restricted because of the cold adjacent metal. In so far, however, as the weld seam forms a narrow zone enclosed between two bands of heated parent metal, the weld seam will be subjected to a tensile load which will produce an extension in the order of magnitude of 2.4×10^{-4}. In view of the magnitude of this deformation, it is inconceivable to assume that the mechanism of deformation of the weld metal which is maintained cold should be identical to the elastic mechanism of the heated base metal. It must be admitted

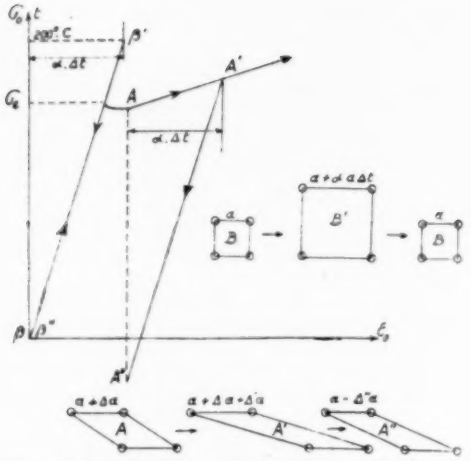


Fig. 4 Schematic representation of the principle of low-temperature stress relieving

Point *A* represents the weld metal: *A* is the weld metal before treatment, *A'* after heating of the parent metal and *A"* after cooling
Point *B* represents the parent metal. The cycle for the parent metal is *B*, *B'*, *B"*

that the metal of the weld seam will deform entirely or partially by gliding. Referring to Fig. 4 it will be seen that if point *A* represents the state of stress in the weld seam before heating, this point will move to *A'* at the end of this operation. The difference of the abscissa between *A'* and *A* represents the extension of the weld seam. The base metal having suffered only elastic strains despite the magnitude of its deformation will assume its initial lattice during cooling and exert a powerful compressive stress on the weld seam. This will have the effect of transforming the parallelogram network into the contracted parallelogram (Fig. 4).

This operation is characterized by the fact that no plastic deformation is possible in the parent metal, while the parent metal produces a severe expansion in the weld seam which should be entirely plastic. Therein lies the great advantage of the application of heat which is the only process permitting the introduction of large deformations in a metal without requiring recourse to the process of gliding.

From the theoretical point of view this process is remarkable and, in our opinion, will form in the future the process of stress relieving.

The practical application of the process differs from the simple scheme expounded above by the fact that the heating and cooling proceeds progressively. This produces plastic deformations also in the parent metal so that the compressive action on the weld seam is evidently reduced (Fig. 5).

Thanks to the collaboration of the firms Smit of Nimegue and S. A. L'Oxhydrique Internationale of Bruxelles, we have had the opportunity of convincing ourselves of the efficacy of the process. Two plates of 1.8-meter length and 0.7-meter width were welded together by arc welding along the length (Fig. 6). The residual stresses were measured in this seam at several points 30 cm. apart. The results of these measurements are given in Table 1.

Table 1—Stresses Before Relaxation

Points	*Longitudinal, stress, tons/in.²* (S_1)	*Transverse stress, tons/in.²* (S_2)	*Orientation* (α)
B	24.2	1.3	0°
C	26.6	1.6	−5°30′
D	27.0	−3.6	4°
E	26.7	+3.9	0°

The assembly was then subjected to the operation of relaxation and the new stress measurements gave the following results (Fig. 7):

$$S_1 = 3.6 \text{ tons/in.}^2$$
$$S_2 = 3 \text{ tons/in.}^2$$
$$\alpha = 36°$$

3. *Mechanical Stress Relieving.*[15–18] As has already been indicated, this process is based on the elastic force of the parent metal. It is schematically represented by a welded test piece placed into a tensile testing machine with the direction of the weld seam parallel to the test-

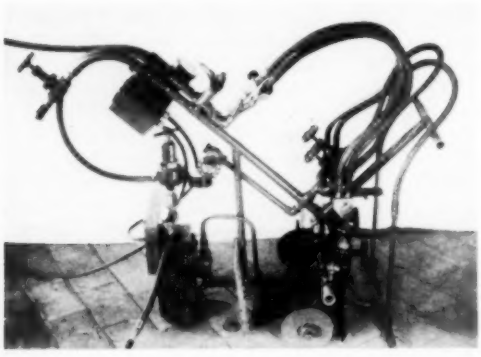


Fig. 5 The Linde apparatus for low temperature stress relieving

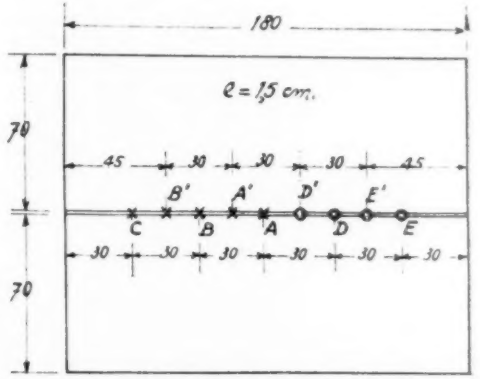


Fig. 6 Plate used for the control of the efficacy of low-temperature stress relieving

Fig. 7 Photograph taken during stress relieving of a weld seam; a hole used for the determination of residual stresses can be seen in the foreground

ing force. On unloading the test piece, the elastic stress stored in the base metal will produce a compressive stress in the weld seam. While this process is of very limited application—in practice it can only be applied to transverse seams in hydraulic vessels and tubes—it is of fundamental importance in the study of the behavior of weld seams under external loading.

This technique which is known in Europe under the name "l'adaptation" has returned to us from the United States under the name of "mechanical stress relieving" and is based on the fundamental hypothesis that the weld seam being in a plastic condition will suffer purely plastic deformation under any external load. When this disappears, the parent metal subjects the weld seam to compression in this way reducing the residual stresses by an amount almost equal to the elastic stresses which existed in the parent metal under the external load. The principle is shown schematically in Fig. 8. We see in this figure that the theory of mechanical stress relieving postulates that Young's Modulus for the weld seam is zero. We have already remarked that this hypothesis is not very probable because the deposited metal is constrained between two bands of metal which deform elastically. The entire discussion on the possibility of low temperature stress relieving hinges on the displacement of the point A_0 when an exterior force is acting on the assembly. The protagonists of the theory of "l'adaptation" assume that the point A_0 will be displaced to A_1 parallel to the X axis. This means that it is supposed that the state of stress in the deposited metal which is already in the plastic state will not be modified, but that this metal being constrained between two bands of parent metal will be forced to suffer the deformations of the parent metal and that these deformations will take place in accordance with the process of constrained gliding. The antagonists on the other hand assume that the point A_0 will be displaced to A_2', similarly as the point B which represents the state of stress in the parent metal. This means that the deposited metal notwithstanding its already severe state of stress will suffer elastic stresses under external loading.

At first glance the theory of "l'adaptation" seems more logical; nevertheless, the elastic deformation assumed by the antagonists of "l'adaptation" is not an impossibility, it is in fact established that the limit of elasticity depends essentially on the state of stress. If this is nonhomogeneous and if, in particular, there are important stress concentrations, the apparent limit of elasticity (the only one in which we are interested is considerably increased and may attain in certain cases twice the value found in homogeneous tension. In order to solve the question one could:

(*a*) Make use of a method of selective investigation which permits one to distinguish between plastic and elastic deformations; the X-ray diffraction method corresponds to this requirement. It is known in fact that the elastic deformations become manifest by a

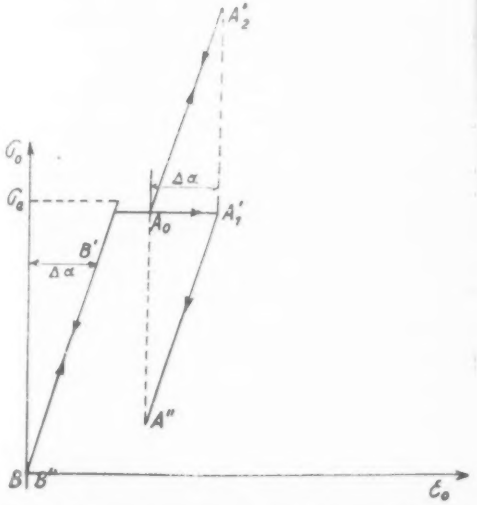


Fig. 8 Schematic representation of the possibilities deformation of the weld metal

A_0, A', A'' is the cycle of the weld metal if adaptation takes place
A_0, A_2', A_0 is the cycle of the weld metal if adaptation does not take place
B_0, B', B'' is the cycle of the parent metal

variation in the diameter of the diffraction ring while the plastic deformations produce line-broadening.

(*b*) Determine the state of stress after having loaded and unloaded the piece. If one finds diminution of the state of residual stresses one can conclude from this that the deformation under exterior forces is entirely or partially plastic.

Our investigations have been confined to these latter investigations and we wish to indicate here the results of some tests. We first of all carried out some tension tests with plates joined by welding, the applied tension being in the direction of the weld.

The first test pieces were made from slightly high tensile (mi-dur) steel 52/62 (tensile strength 33–38.5 tons/in.^{2}) The electrodes were of the soft variety. These conditions are in fact most favorable for producing plastic deformations in the weld metal without plastic deformations appearing in the parent metal.

The residual stresses were measured in depth before and after relaxation. The tensile force applied to the test piece was fairly large and corresponded to stresses of the order of 20 tons/in.^{2} These values were very near to the limit of elasticity of the parent metal. The results are given in Table 2.

Table 2

Principal Stresses Before Loading

Depth, mm.	*Principal stresses, tons/in.^{2}* S_1	S_2	*Directions,* α_0
1	14.6	2.2	+10
2	18.7	1.0	+18
3	22.2	4.1	− 5
4	14.0	0.8	− 8

Principal Stresses After Applying Tensile Stress Followed by Unloading

Depth, mm.	*Principal stresses, tons/in.^{2}* S_1	S_2	*Directions,* α_0
1	14.6	6.7	− 3.5
2	4.3	1.3	+13
3	2.2	0.1	−17
4	2.2	0.1	+22

The figures show that under this very high load the residual stresses were effectively reduced.

Analogous experiments were carried out with mild steel specimens but with less success. After having applied a tensile stress of 12.7 tons/in.^{2} to the test piece, residual stresses of $S_1 = 13.2$ tons/in.^{2} and $S_2 = 3.5$ tons/in.^{2} were still found.

In view of the practical interest of the method for the stress relief of transverse seams in cylindrical vessels, we have also made some tests on vessels. The first was a mild steel cylinder for compressed gas. This cylinder was cut and rewelded with mild steel electrodes. The welded vessel was subjected to a pressure of 3500 psi., which produced in the transverse weld a stress of 23 tons/in.^{2} After unloading, the residual stresses were measured in the weld seam. These were found:

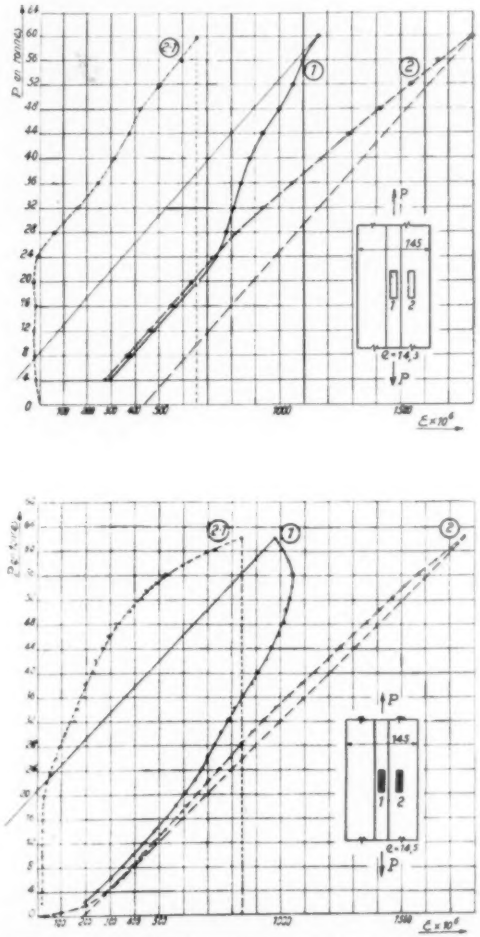
$S_1 = 6.4$ tons/in.^{2}
$S_2 = 2.5$ tons/in.^{2}

This means that a considerable reduction had taken place. A similar test was carried out on a small mild steel vessel, the pressure for which relaxation took place was 980 psi., producing a transverse stress of 11 tons/in.^{2} After unloading, the following stresses were found:

(*a*) In the transverse seam:
$S_1 = 8.1$ tons/in.^{2}
$S_2 = 2.2$ tons/in.^{2}

(*b*) In the longitudinal seam:
$S_1 = 13$ tons/in.^{2}
$S_2 = 1.6$ tons/in.^{2}

(*c*) In the intersection of the two seams:
In the direction of the transverse seam, 19.05 tons/in.^{2}
In the direction of the longitudinal seam, 3 tons/in.^{2}



Figs. 9 and 10 Tensile test on longitudinal weld seam: Curve 1 represents the deformations of the weld metal; Curve 2, those of the parent metal

From these tests it seems to follow that a reduction in the residual stresses can be obtained by external loading on condition that the external load is sufficiently big; the relaxation seems more efficient for high-tensile steels welded with mild steel electrodes than for mild steels. In order to gain a clearer insight into the phenomenon of relaxation we placed resistance strain gages on the seam in the longitudinal direction and on the base metal. By using a dummy gage it is possible to measure the absolute value of these deformations and by using, for instance, the strain gage placed on the parent metal as a dummy one measures directly the difference between the strains in the base metal and the weld metal. We have made use of this arrangement for different test pieces. The diagrams in Figs. 9 and 10 give the results of the measurements carried out on tensile specimens prepared from mild steel; in these stress-strain diagrams two parts can be distinguished. In the first part the deformations of the parent metal are practically identical with those of the weld metal. We shall not further consider the process of these deformations. Beginning with a stress which for the test pieces under consideration was of the order of 7.6 tons/in.^{2} it can be observed that the deformations of the weld metal are no longer equal to those of the parent metal but become smaller. In the diagram of Fig. 10, it can be seen that, for a stress of 16.5 tons/in.^{2} this deformation changes sign. This finding has surprised us so much that we have examined the possibilities of continuing the measurements above the apparent limit of elasticity, but since resistance strain gages attached in the direction of the tensile load do not permit measurements to be obtained above the limit of elasticity of the parent metal, we were led to carry out tensile tests on plates joined by welding in which the weld seam was inclined to the direction of loading in such a way that the elastic strains measured in this direction were very small but still positive. This arrangement has permitted us to plot the stress-strain curve right up to rupture. The diagram in Fig. 11 gives the results of a test carried out with high-tensile steel. The two diagrams have the characteristic form of an S curve. This means that while the strains in the parent metal increase regularly those of the weld metal increase up to a certain stress, 14 tons/in.^{2} for mild steel and 17 tons/in.^{2} for high-tensile steel, and then diminish to increase once more up to rupture. We explain this phenomenon by the appearance of a very localized flow in the base metal.

Supposing that in conformity with modern theories of plasticity a glide plane appears in the parent metal, automatic unloading will be produced in the parent metal and in the weld metal; this phenomenon, however, will not be perceptible from the indicating pointer of the testing machine unless the gliding is sufficiently large for the inertia of the machine to be overcome. These first glides are so small that this will be generally impossible, but, as distinguished from the testing machine, the residual stresses in the weld react immediately to this phenomenon and profit from it in a partial liberation. The residual stresses are therefore extremely sensitive indicators for even the most feeble manifestations of gliding. It seems to result, therefore, from these experiments that relaxation of residual stresses produced by exterior loading is not due to plastic deformation in the weld metal but rather to plastic deformation in the parent metal. This conclusion at the same time explains the necessity for imposing very high

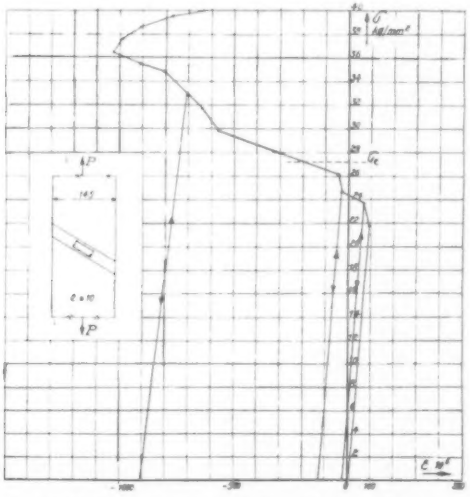


Fig. 11 Tensile test on inclined weld seam: The curve represents the deformations of the weld metal (mild steel)

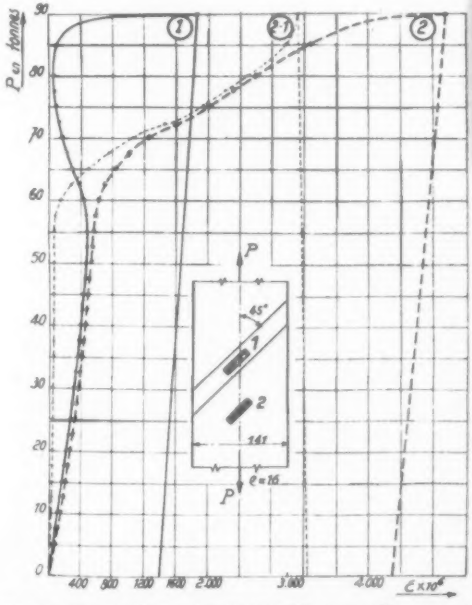


Fig. 12 Tensile test on inclined weld seam: The curve 1 represents the deformations of the weld metal (high-tensile steel), curve 2, those of the parent metal

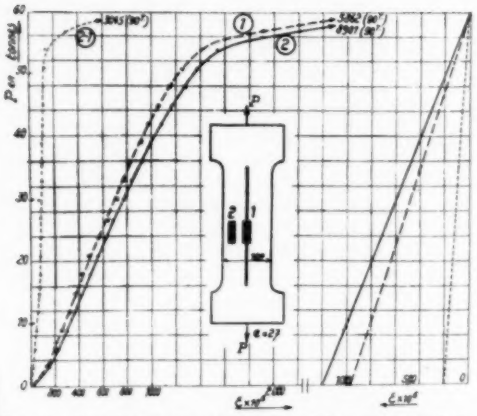


Fig. 13 Tensile test on a test piece with a weld bead deposited in a longitudinal groove: The curve 1 represents the deformations of the weld metal, curve 2 those of the parent metal

stresses on the welded assembly before the effect of residual stress relaxation can be observed; but in as far as the appearance of the first glide planes is more or less accidental and since the plastic deformation of the parent metal must be considered more or less a partial destruction of the welded assembly, it appears to us that this operation is dangerous. The accidental character of plastic yield by local flow can be further illustrated in the following diagrams.

The diagram in Fig. 13 gives the deformations of a test piece with a weld bead deposited in a longitudinal groove; this only extends over the central part of the test piece whose ends are splayed. In this arrangement the appearance of localized plastic deformation near the jaws of the tensile testing machine is not credible. The diagram shows that the deformation of the parent metal and the weld metal are identical.

The diagram of Fig. 14 gives the deformations in a pure bending test of two plates joined by a longitudinal weld. The appearance of accidental gliding is not very probable in consequence of the arrangement used and the stress gradient existing in the direction of the depth. The results of the test reveal no difference between the deformations of the parent metal and that of the weld metal.

(E) Direction Superposition of a State of Compression

1. General. If it is desired to reduce the residual stresses in a weld seam which is subject to high-tensile stresses in its longitudinal direction by superimposing directly a state of compression, it would suffice to subject the seam in its longitudinal direction to a compressive load, so that the plastic deformations after unloading maintain compressive stresses in the weld which reduce the state of final tension. This process is, however, not applicable in practice quite apart from difficulties of execution; the danger of buckling limits its application. Partial results can be obtained by bending when one of the faces of the weld seams is subjected to plastic compression, although the other face will suffer an additional tension. In the case of hard-surfacing, this process may be useful. It is, however, not impossible that in applying this compressive load for a small length by proceeding from point to point one gets results by employing an oxyacetylene flame. But the processes used in order to superimpose a state of compression cannot act directly along the axis of the weld seam but are applied to the surface of the plate. Actually the engineer has at his disposal a number of processes for the creation of compressive stresses in a piece. We cite:

1. Physico-chemical processes; cementation, nitration, surface quenching
2. Mechanical processes:
   (a) Static compression: α by a press; β by a roller
   (b) Dynamic compression: α by peening; β by shot blasting

The favorable influence of mechanical treatment on the behavior of metals has been known for a long time. We should like to refer here to a passage in a study by Almen which appeared in *Metal Progress* in 1943. "The idea of surface compression to improve strength of steel is probably as old as steel itself. It has probably been discovered, forgotten and rediscovered many times. Certainly every village blacksmith knew and practiced the art in making wagon and buggy springs, axles and other heavily loaded parts. After these parts were forged into shape they were severely hammered to improve their strength and no doubt, the same procedure was followed by the ancient sword makers, likewise mill and ship shafts were cold worked by the application of small rollers at high pressure, after machining, because of the greater strength that was known to result."

The mechanical processes have the following consequences.

1. To create compressive stresses in the surface layers;

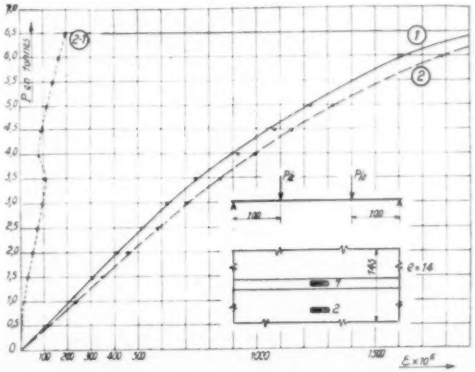


Fig. 14 Pure bending test of two plates joined by a longitudinal weld.: The curve 1 represents the deformations of the weld metal, curve 2 those of the parent metal

2. To attenuate surface notches;
3. To work-harden the metal on the surface.

These treatments are generally applied either to increase fatigue resistances or to increase corrosion resistance. Engineers are, however, not entirely in agreement on the cause of the improvement produced in the metal. Certain authors (like Thum in Germany and Almen in U.S.A.) claim that the improvement is due to compressive stresses, others like (Föppl) claim, on the contrary, that improvement is due to work-hardening and to the disappearance of surface notches. In order to check the efficacy of the treatment we cannot base our judgment on the results of fatigue tests but solely on direct measurements of residual stresses. Such publications are, however, still rare, the majority of the authors having confined themselves to the study of the increase in fatigue resistance after the application of one of these processes.

Of all the processes mentioned above only the mechanical ones have been applied to welds with a view to reducing the tensile stresses in the welds.

2. Mechanical Processes. All mechanical processes are based on creating compressive stresses by plastic deformations. The systematic application of these processes requires knowledge of the laws of plasticity; these unfortunately are not known. The result of this is that all these processes are empirical and that their effect can only be verified by way of experiment. The first problem which is posed by the application of these processes to welds is the problem of determining the location where it is necessary to effect compression. It it necessary to compress the weld seam or the adjacent parent metal? In order to answer this problem it is necessary to carry out strain measurements in the metal which has been directly subjected to the operation of compression and in the adjoining metal.

In order to study the deformation in the neighboring metal it is sufficient to make impressions at the ends of a resistance strain gage which will record the deformations in the metal adjacent to the impression.

For metal work-hardened by peening one may, if the impression is sufficiently large, determine the residual stresses by one of the methods described but if the size of the impression does not permit this one has recourse to the X-ray method.

In practice surface compression is carried out by one of the following processes:

(*a*) Static compression with rollers: In order to reduce the compressive force the cylindrical impression is obtained by a roller and the process carried out step by step. Already before the war there was a German patent based on the use of rolling to increase the fatigue resistance of welds. The Germans were content to compress the transition zone by moving the rollers parallel to the weld seam (Fig. 15). We have no knowledge of residual stress measurements but fatigue tests carried out with test pieces treated in this way showed an improvement of 72%; all the test pieces broke in the parent plate removed from the weld.

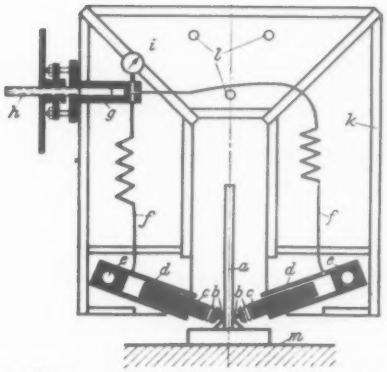


Fig. 15 Diagram of a German apparatus used for increasing the fatigue resistance of fillet welds

The working conditions were as follows:

Radius of curvature of the roller: 2.5 mm.
Load: 500 kg.
Size of impression: 2.5 mm. This was obtained in three or four passes.
Depth of impression: 0.5 to 0.7 mm.

The Americans are making current use of this method to increase the fatigue resistance of components subjected to rotary bending. The methods of working are practically identical to those used by the Germans. In a study made by D. Richards[19] the author publishes results of residual stress measurements obtained after treatment by rolling. By moving the roller in the longitudinal direction of the test piece compressive stresses of 13.3 tons/in.^{2} were measured; these are practically independent of the compressive force. The author has found that the maximum compressive stress does not occur in the extreme fibers but at a depth of the order of 0.5 mm. By moving the roller in the transverse direction the stresses reach a value of 25.4 tons/in.^{2} and were a maximum at the outside fiber (Fig. 16).

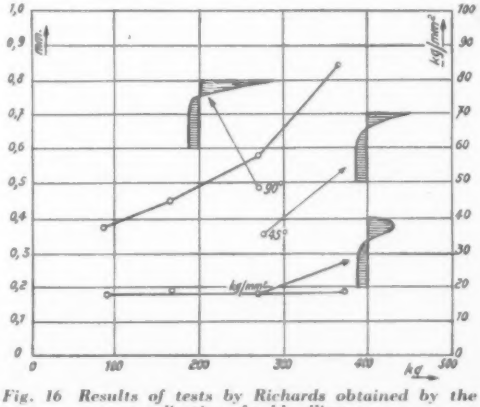


Fig. 16 Results of tests by Richards obtained by the application of cold rolling

(*b*) Dynamic compression: By hammer peening; we consider here only cold peening. This operation has provoked much controversy, the following considerations make it possible to appreciate the difficulties encountered in practice if satisfactory results are to be obtained. The most important factors in peening are the form of the tool and the technique used. The use of a hammer with a spherical head make the operation very difficult. It is inevitable that in certain places very high tensile stresses are engendered by this operation which may even provoke cracks. Experiments carried out by Thum and Erker confirm the practical difficulty of this operation.

A more rational application of peening due to de Garmo, Jonassen and Meriam[20] has produced very interesting results. These authors have used a cylindrical mass which they have moved in a direction normal to that of weld hammering the seam and the parent metal for a width of 50 mm. on both sides of the seam. In this way they have reduced the longitudinal stresses from 24 tons/in.^{2} to 8.2 tons/in.^{2}

In view of the great care which has to be exercised in the application of peening and the large amount of work required, peening will probably never become an ordinary stress-relieving treatment.

Shot peening, shot blasting: [21–23] The regularity of peening and the working time can be greatly improved by projecting steel splinters on the surface to be treated. This operation, especially when applied to relatively small pieces, is used a great deal in the U.S.A. In as far, however, as the impressions are smaller than those obtainable by hammer-peening, the depth of the compressed zone is small. Shot peening, therefore, finds its application in welding for mechanical engineering components which are machined and which must possess high fatigue resistance. It follows from the results of measurements carried out by D. Richards that by means of a judicious choice of the variables it is possible to obtain from shot peening compressive stresses of 29 tons/in.^{2}, with a compression zone of 7 mm. depth.

Figure 17 gives some results obtained by this author.

Of all the mechanical processes, the use of cold rolling seems the most commendable and practical. It would be desirable for a systematic study to be carried out which would permit the assessment of the efficacy of this process when applied to welds.

V. CONCLUSIONS

In the second part of our lecture relating to the relaxation of residual stresses we have only one aim; to show the urgency for certain researches to be carried out. It is a fact that the requirements of construction do not wait for the results of laboratories. This is why one finds more and more often specifications in which stress relieving heat treatment is one of the requirements for welded structures. The fabricator is obliged to accept this condition, which inevitably increases the cost of the welded structure, while in the laboratory one has not yet been able to show the effect of shrinkage

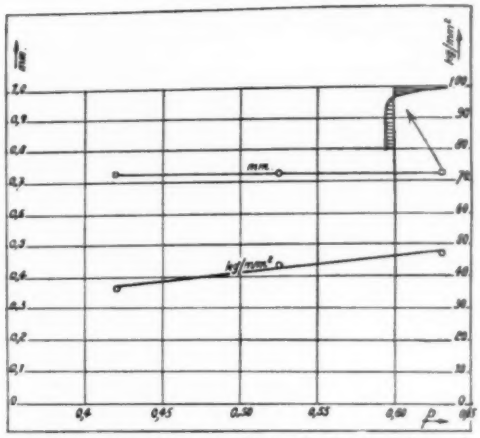


Fig. 17 Results of tests by Richards obtained from the application of shot blasting

stresses. By admitting that this influence may be deleterious is it not the duty of our Institute to carry out a comprehensive investigation of all the processes of relaxation in order to choose the best one and the cheapest one? It is possible that heat treatment in the furnace is the most radical process but it is certainly not the most economical.

Bibliography

1. Symposium on Internal Stresses in Metals and Alloys, The Institute of Metals, October 1947.
2. Orowan, E., "Classification and Nomenclature of Internal Stresses," p. 47, reference 1.
3. Soete, W., "Détermination semi-graphique des tensions internes au moyen des cayons X," *Ann. Trav. Pub. Belg.* (Feb., 1943).
4. Soete, W., "Bepalen van Eigenspanningen," *Metalen* (July 1948).
5. Soete, W., and Vancrombrugge, R., "Een quasi niet destructieve Workwijze tot het bepalen van Eigenspanningen," *Rev. Soudure-Lastijdschrift*, No. 4, 1947.
6. Soete, W., and Vancrombrugge, R., "Het meten van Eigenspanningen in Diepte," *Ibid.*, No. 1, 1948.
7. Soete, W., and Vancrombrugge, R., "Détermination des tensions résiduelles dans quelques constructions soudées," *Ossature Metallique*, No. 5, 1948.
8. Weck, R., "L'etat actuel des tensions residuelles en constructions soudées," *Rev. Soudure-Lastijdschrift*, No. 3, 1948.
9. Ros, M., "Die Gleichwertigkeit der Schweissung mit der Nietung und mit dem vollen Blech," *Smit-Inzenaute*, June 1948.
10. "Fatigue Strength of Butt Welds in ordinary Bridge Steel" Progress Report III of the Fatigue Testing Committee, The Welding Journal, **22** (5), Research Suppl., 189-s to 211-s (1943).
11. Patton, E., and Gorbunov, B., and Bernstein, D., "Les Tensions de retrait dans les Reservoirs cylindriques soudés," ossature Métallique, **7**, (1), p. 29-39, (1938).
12. Evans, U., "Influence of Residual Stress on Chemical Behaviour," p. 291, reference 1.
13. Keating, F., "Chemical Manifestations of Internal Stresses," *ibid.*, p. 311.
14. Greene, T., and Holzbaur, A., "Controlled Low-Temperature Stress Relieving," The Welding Journal, **25** (3), Research Suppl., 171-s to 185-s (1946).
15. Meriam, J., de Garmo, E., and Jonassen, F., "Redistribution of Residual Welding Stresses by Tensile Loading Along a Unionmelt Weld, Joining Two 3-Ft. × 12-Ft. ×1-in. Plates," *Ibid.*, **25** (10) Research Suppl., 697-s to 699-s (1946).
16. Roop, W., Discussion of paper "Redistribution of Residual Welding Stresses by Tensile Loading Along a Unionmelt Weld, Joining Two 3-Ft. x 12-Ft. x 1-In. Plates," *Ibid.*, **26** (2), Research Suppl., 127-s to 128-s (1947).
17. McCutcheon, E., Discussion of paper "Redistribution of Residual Welding Stresses by Tensile Loading Along a Unionmelt Weld, Joining Two 3-Ft. x 12-Ft. x 1-In. Plates," *Ibid.*, **26** (3), Research Suppl., 138-s (1947).
18. Vasta, J., Discussion of paper "Redistribution of Residual Welding Stresses by Tensile Loading Along a Unionmelt Weld, Joining Two 3-Ft. x 12-Ft. x 1-In. Plates," *Ibid.*, **26** (3), Research Suppl., 191-s to 192-s (1947).
19. Richards, D., "A Study of Certain Mechanically Induced Residual Stresses," *Proceedings S.E.S.A.*, Vol. III, No. 1.
20. de Garmo, P., Jonassen, F., and Meriam, J., "The Effect of Peening Upon Residual Welding Stresses," The Welding Journal, **25** (10), Research Suppl., 616-s to 623-s (1946).
21. Humfrey, J., "Stresses Induced by the Shot Peening of Leaf Springs," p. 189, reference 1.
22. Moore, H., "A Study of Residual Stresses and Size Effect and a Study of the Effect of Repeated Stresses on Residual Stresses Due to Shot Peening of Two Steels," *Proceedings S.E.S.A.*, Vol. II, No. 1, p. 170.
23. Horger, O., and Neifert, H., "Improving Fatigue Resistance by Shot Peening," *Ibid.*, p. 178.

Welding Rails on Ship Model Towing Basin

Procedures for welding 165- and 180-lb. rails are indicated for avoiding undesirable metallurgical changes. Alignment requirements favor the butt joint

by W. J. Leonard

Abstract

Pilot tests were made on welding 165- and 180-lb. rails 32 ft. in length having a flame-hardened head surface and requiring a longitudinal alignment within ±0.002 in. at the welded joint. These rails are cut in a 45° miter angle in the head, being a 90° butt joint in the base. Tests made indicated that satisfactory welds could be made on this miter-type joint with minimum metallurgical changes in the rail steel at the joint. However, the thin corners on the mitered joint could not be held within the alignment requirements. A 90° butt joint welded by the same general procedures met the alignment requirements as well as hardness and metallurgical requirements. Batter tests made on the resultant welded joints indicated a superiority for the butt joint under simulated service conditions.

INTRODUCTION

THE rails used in the development of welding methods for later application on the towing basin were originally purchased for use with mechanical joints. These rails were 32 ft. in length, and were cut at each end by a 45° miter cut across the head while the base was a 90° cut at each end. A heavy towing carriage using either electric-hydraulic drive or electric-motor drive operates on these rails at speeds up to 25 mph. Subsequent development of new higher speed carriage design with preloaded pairs of side driving wheels, as well as driving wheels on the top rail surface, indicated the desirability of a joint stronger than was possible to obtain using a mechanical type joint.[1] A 30 ft. length of the original rail was cut into shorter lengths and made available for experimental welding using the same 45° miter joint at the ends. The 165-lb. rails possessed a flame-hardened surface across the width of the rail head extending inward to an average depth of 3/16 in. The 180-lb. rails had this same flame-hardened surface extending down the side surfaces of the rail head in addition to the top. The rail steel had an average analysis of 0.78% carbon and 0.85% manganese and the surface hardness on the flame-treated head surface varied from 31 Rockwell C scale to 37 Rockwell C scale. The rails are secured to cast-iron chairs by means of threaded studs, extending from the chairs through drilled holes in the flange of the rails at 8-in. intervals of length, which secures the rail to the chair by tightening down with nuts. Vertical lugs exist on the chairs giving a sufficient clearance between the base of the rail and lugs to permit welding of the rail in position. The chairs are imbedded in concrete base for strength and rigidity. The rails are aligned longitudinally to tolerances of ± 0.001 in. with maximum offsets of 0.002 in. occurring at the joints. The top of the rail head has maximum vertical offsets of 0.001 in. occurring at the joints as aligned on the basin. The basin rails are shown in Fig. 1 under operating conditions.

The welding development tests were undertaken to develop a means of joining these rails on the basin obtaining the same exacting alignment results; minimum hardness change in the flame-hardened surface; a weld deposit of equal hardness to the rail steel and minimum metallurgical changes in the rail steel at the welded joint.

HARDNESS AND ALIGNMENT RESULTING FROM WELDING

Two short lengths of 165-lb. rail—20 and 8 in., containing 2 sets and 1 set of bolt holes, respectively—were mounted on a spare basin chair which had not been set in concrete. The rail ends where the joints were to be connected by welding were in the previous mitered condition as received from the contractor. A J- or U-groove, shown in Fig. 2, was used on both the top surface and side of the rail head.

The joints were aligned longitudinally by means of a level bar micrometer indicator until the alignment difference between the side surfaces of the rail head was less than 0.001 in.—the gap between the joints was 5/32 in. measured longitudinally along center lines of the rail. A 5/32-in. low-carbon steel shim plate was placed in the gap to act as a backing plate for the weld metal. The nuts securing the rails to the chair were tightened to a tension of 100 ft.-lb. on the chair studs, by means of a torsion-meter dial wrench. Punch marks 5 in. from the center of the joint on both the top and sides of the heads of the two rail sections were drilled out to a depth of approximately 1/16 in. to fit the attachment of a 10-in. Whitmore mechanical strain gage. Room temperature strain readings were taken.

The joint was heated by an acetylene torch until an average temperature of 850° F. was measured by means of a contact pyrometer in the center of the

W. J. Leonard is Materials Engineer, Taylor Model Basin, Navy Dept., Washington 7, D. C.

Fig. 1 Photograph of towing basin showing carriage and tracks

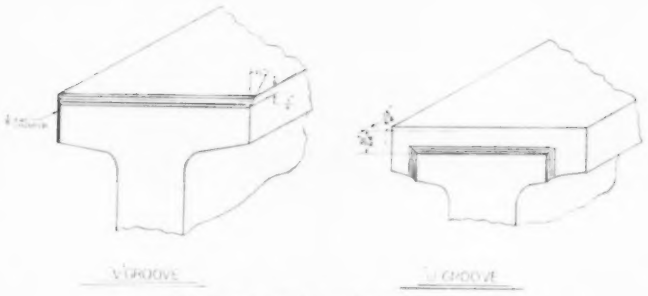


Fig. 2 Groove design for welding tests

top and side head surfaces. The sharp corners of the mitered joint were heated to a higher temperature momentarily due to small mass in direct contact with the torch. The filler metal, which was a 19-9 stainless steel, was then deposited using $^1/_8$-in. electrodes and reversed polarity d.-c. current. Passes were made in succession across the top of the head and down both sides; then in the fillet in the flange on each side. This was repeated until the groove was completely filled with weld metal. Measurements were made at various times during the test to observe expansion and contraction during the process. Results are shown in Table 1 in comparison with rails in initial unwelded condition.

on the rail steel in the transition zone. A maximum reading of 30 Rockwell C was obtained on the weld metal at this juncture, while the weld metal had a hardness range of 16 to 25 Rockwell C away from the juncture.

The finished weld as machined flush to the rail was given a shear test by a force applied through a steel block from a large tensile testing machine. The rail was bolted down to a heavy bed plate with a steel bar support against one side of the head the other being unsupported. A load of 225,000 lb. was applied on the opposite side of the head on the unsupported side of the joint. No measurable yield or deflection was obtained. After removal

Table 1—Strain Gage Changes of Length on Welding and Cooling

	Side, in.	*Top, in.*	*Side, in.*
Length change on preheating to 800° F.	0.0269	0.0312	0.0248
Length change on completion of welding and cooling to room temperature	−0.0365	−0.0344	−0.0351

The sharp thin outside top section in the head of the rail mitered joint buckled inward due to heat, a distance of 0.004 in.

Hardness readings were made on the welded joint after the weld metal was ground down flush to the top-rail surface. Starting at a distance about 2 in. back from the weld metal and proceeding longitudinally along the rail into the weld metal making hardness readings, indicated very little change from the readings taken before welding. Hardness on the acute miter angle did change appreciably. Minimum hardness reading of about 17 Rockwell C and 21 Rockwell C were recorded about $^1/_4$ in. from the weld metal. The sharp corner was thought to have been over the critical temperature of the steel at sometime during the preheating and welding, resulting in air hardening at the extreme tip. Hardnesses of 40 Rockwell C were recorded on this corner. At some positions a very narrow transition area less than $^1/_{64}$ in. was obtained by hardness readings at the junction of the weld metal and rail head. Maximum hardness readings of 40 Rockwell C were obtained

of the welded rail section from the bed plate, measurements indicated no change of alignment at the joint.

A 6-ft. rail length and a 5-ft. 4-in. rail length were cut and the end joints were prepared for welding as shown in Fig. 2 using the single V-groove. These joints were placed on a 12-ft. basin chair, the joint occurring at the mid-point of the chair, and secured lightly by bolts and wedges. They were aligned until the differences between the side surfaces and top surfaces of the rail heads were less than 0.001 in. The gap between the rail sections at the base of the V-groove was $^3/_{32}$ in. measured longitudinally along the center line of the rail and contained $^1/_{16}$-shim backing plate. The nuts securing the rails to the chair were then tightened by a pull up of 200 ft.-lb. This is somewhat greater than the average tension of bolts in the basin. Ten-inch Whitmore strain gage readings were made as in the former test.

The rail joint was heated continuously for approximately 12 min. Contact pyrometer temperature measurements gave 400° F. in the center of the top and side

head surfaces of the rail. This temperature seemed to be the practical maximum attainable using one torch with the present setup. The filler metal, which was deposited in passes made in succession across the top of the head and down both sides, thence in the fillet in the flange on each side, was a 19-9 stainless-steel electrode. A $^3/_{32}$-in. electrode was used for the first pass in the head of the rail; $^1/_8$-in. electrode for all subsequent passes. The third and last pass made in the head of the rail was with an electrode called "Frogalloy" commercially, which is a stainless steel containing approximately 21% chromium, 8% nickel, 4% manganese, 0.08% carbon, balance iron and impurities. A sufficient amount of weld metal was deposited so that the weld metal overlayed the rail steel. All passes were peened except the last. Temperature on the rail head adjacent to the weld were maintained at about 300° F. by frequently heating the joint by torch before and after placing metal. Measurements made by strain gage showed an average increase of 0.009 in. in length on preheating and a total average shrinkage of 0.014 on cooling of the weld metal to room temperature. The alignment remained the same as before welding, the welded section was loosened from the chair and placed on a machine planner bed and measured free. A lateral bow of 0.010 in. was present at the joint while a vertical bow of 0.040 was measured, the ends of the rail moving up this amount. It was not known whether the resulting lateral bow in the rail was present before welding on the chair or not. It was expected that the welded rail segment would tend to buckle up slightly on the terminals when free, due to the volume of weld metal placed in the upper surface of the rail head.

The weld was then machined flush to the rail head and given a shear test as before. The rail began to yield in the head at about a 200,000-lb. load, while at the same time the flange split across at a 45° break almost directly under the head weld. The head fractured at a 216,000-lb. load.

Rail sections 4 in. shorter than before with the same joint dimensions as before were prepared, however, the method of alignment was entirely different. A stainless-steel sag wire was stretched over the length of the chair between two holders, which were mounted on the basin chair in prearranged drilled holes in the chair. The steel sag wire was aligned parallel to the center line of the chair. The rails were aligned as before approximately parallel to the chair. Then a special microscope attachment is mounted on the rail head at an extreme end of the rail and the distance from the center of the rail head to the sag wire is read by means of the microscopic eyepiece. This attachment is moved along the entire length of the rail while the rail is moved transversely

as necessary by means of the wedges between the rail flange and chair. When a constant reading on the microscope scale is obtained at all positions along the rail length, the rail is aligned parallel to the chair attachment. This alignment assembly is the same apparatus used to place chairs in the basin channel walls and align rails on the chairs.

In order to measure the level of the rail and chair along the length, a 10-ft. straight edge was calibrated for sag and placed on two ground blocks 0.3125 in. in thickness. By means of a slightly smaller ground block and feeler gages the level reading on the chair and rail were measured along the length of the rail and chair. The alignment, level and strain gage readings were made and recorded with the rail placed and bolted down in its final prewelded condition.

The welding procedures were the same as before except that, only the first weld pass in this test was made with 19-9 stainless electrode, all others being made with Frogalloy. The temperature was maintained at or slightly above, 450° F. throughout the welding. The average contraction due to weld metal shrinkage was 0.017 in. in this test compared to 0.014 in. in the previous one.

The bending or transverse movement due to welding while the rail was secured was less than 0.002 in. at original position along the rail length. On freeing the rail by removing wedges and bolts a bow of 0.015, measured between the ends and joint of the section, resulted from residual stresses induced by welding. This welded section was 11 ft. 4 in. in length. Level measurements showed maximum changes of 0.002 in. at some positions along the welded section.

HARDNESS AND MICROGRAPHIC CONSTITUENTS PRESENT AT THE WELD METAL-BASE METAL INTERFACE

A 0.01 in. machine cut was taken off the top of the rail so as to give a sharp line of demarcation between the filler metal and the rail steel. Hardness reading before and after machining showed no difference. At a few positions along the rail adjacent to the weld metal a transition hardness zone shows up using the Rockwell hardness diamond tester, but most positions do not indicate a hardness transition zone. Three adjacent positions gave Rockwell C hardness of 55, 53, and 51 on the rail steel at the extreme edge of the metal junction and hardness up to 41 Rockwell C were obtained on the filler metal at the extreme edge of the junction. By viewing the indentations through an eight power glass at the foregoing discernible hardness transition zones, a hardness of about 40 Rc is obtained at a distance of $^1/_{64}$ in. from the boundary. Between this point and the boundary

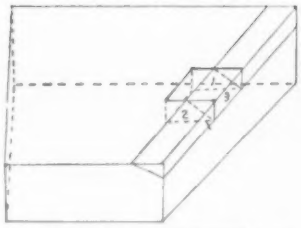


Fig. 3 Section for microscopic examination

the hardness increased to their maximum as the boundary was approached and fell off to an average value of about 30 Rc the same distance in the opposite direction. The weld-metal hardness fell to a value of about 32 Rc at a distance of less than $^1/_{64}$ in. from the interface. The average rail-steel hardness varied from 32 to 38 Rockwell C, while the average weld metal varied from 25 to 30 Rockwell C on the top surface of the rail. The rail-steel hardness varied from 30 to 33 Rockwell C, while the average weld metal varied from 22 to 26 Rockwell C on the side surface of the rail.

A section was taken from the center of the top rail surface shown in Fig. 3 from which no discernible transition zone could be obtained with the Rockwell hardness tester. This section was considered to be a typical representative area of the weldment. It was sectioned into three sections showing a longitudinal top view, a longitudinal side view and a transverse section. Microscopic examinations were of: (1) showing junction of the last layer of weld metal and rail on top surface; (2) showing successive layers of weld metal and junction of all passes of weld metal and rail; (3) showing successive layers of weld metal and junction of initial pass of weld metal and rail in root opening. Knoop hardness measurements were made with a Tukon hardness tester using 100-gm. loads.

A hardness indentation was made on No. 1 at the boundary and the areas adjacent to the boundary as shown in Fig. 4. A transition zone of about 0.080 in. was evident in the rail steel and the weld metal showed a higher hardness adjacent to the juncture. The scatter of Knoop values is typical as it must be remembered that the indentations cover less than 0.002 in. and in an area of heterogeneous microscopic constituents of different hardnesses each constituent will reflect its inherent hardness on the resultant Knoop number. The comparable Rockwell C hardness at the boundary and in the edge of Zone 1 is about 37, increasing to 42 in the interior of Zone 1. Zone 2 averaged about 42 Rc while Zone 3 averaged about 44 Rc. The untransformed base metal showed a slightly annealed area of about 0.008 in. adjacent to Zone 3. Hardness adjacent to Zone 3 was about 35 Rc while the untransformed rail had a hardness of about 37 Rc. The weld metal had a comparable Rockwell C of 41 adjacent to the boundary falling off to 33 at a distance of 0.020 in. from the boundary. The Rockwell C hardness varied between 26 and 33 for the average weld-metal structure.

Figure 5 is a comparable micrographic area on the same sample as the hardnesses of Fig. 4. The same heat-affected zone was obtained and the three transition zones comprising it are shown by metallographic procedures. This sample (No. 1) contains the junction of the last pass of

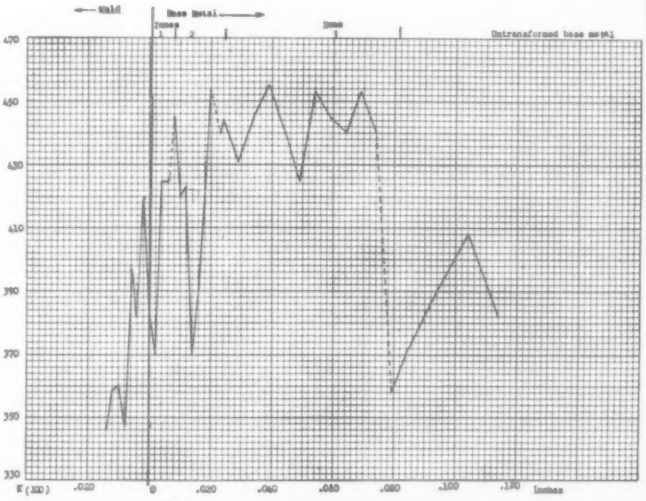


Fig. 4 Knoop hardnesses on top longitudinal surface of welded rail

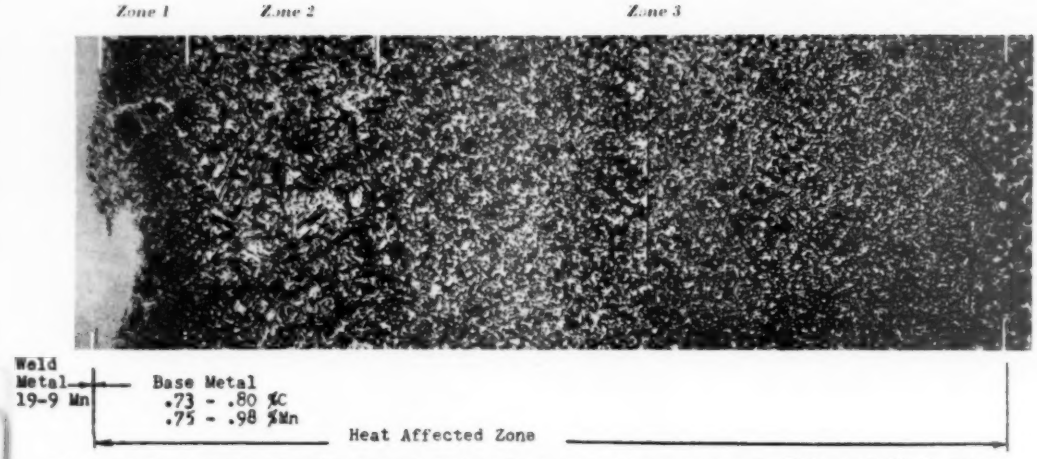


Fig. 5 Photomicrograph of weld metal-rail interface showing transition zones in rail. Etchant 3% Nital. 100 ×

weld metal and the top of the rail showing it to be entirely sound and satisfactory. The junction was practically a straight line all along the interface with few exceptions. The hardness results of Fig. 4 were taken along a line normal to a typical straight-line junction. Figure 5 is a photomicrograph taken at one of the few jagged interface positions. The austenitic weld metal (unetched) can be seen extending into the base metal in intercrystalline rivulets along many positions of the interface for an average distance of about 0.002 in. The cavity into the base metal was probably made by arc melting some of the base metal away with consequent physical mixing of liquid base metal and liquid weld metal. The peninsula of base metal jutting out is probably a solution of Zone 1 metal containing solidified-austenite. The products of Zone 1 exhibit a tempered martensite structure with fine unresolvable carbides. This zone was probably considerably enriched in alloy content by liquid weld metal as well as diffusion, so it is not surprising that its microscopic appearance is very much like an intermediate alloy-tool steel. This extreme edge was heated above the critical and refined similar to Zone 3 by the preceding pass, and at or close to liquidus temperature during the weld metal deposition. It again reached a temperature slightly below or at the critical during the subsequent pass. This constituent is shown at higher magnification in Fig. 6 (*A*) and should exhibit a high strength and toughness to both static and impact loading.

Zone 2 is very much like Zone 1 in constituents being tempered martensite and fine unresolvable carbides without the added alloy content from the weld metal. This zone probably was slightly under the critical temperature during the preceding pass but reached a temperature considerably above the critical during the deposition of weld metal. It crystallized in the cleavage-type pattern typical of the cooling of a high temperature austenite through the transition temperature range at the critical rate necessary for the Widmanstätten structure. The remaining austenite transformed to martensite at

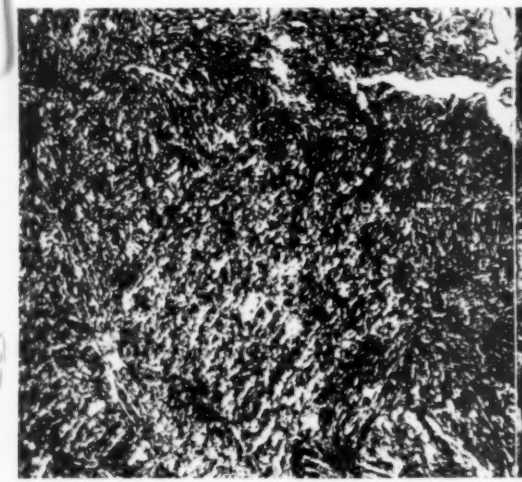


Fig. 6 (A) Showing Zone 1 with the weld metal extending into base metal (upper right corner). Etchant 3% Nital. 500 ×

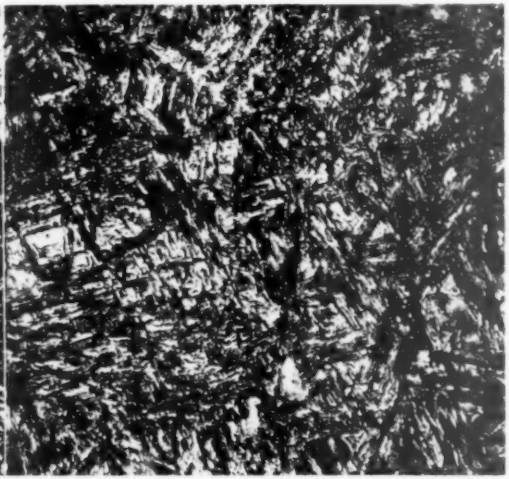


Fig. 6 (B) Showing cleavage type structure resulting from precipitation of martensite and transitions products along the octohedral planes of the original austenite. Zone 2. Etchant 3% Nital. 500 ×

lower temperatures in the same type pattern. The subsequent pass tempered this structure. The Knoop hardnesses indicate the nonhomogeneity of this structure. This structure should have a good static strength but is the least desirable structure present for withstanding impact loading.

Zone 3 was not heated above the critical by either the preceding or subsequent pass although the area adjacent to Zone 2 may have been tempered some by the subsequent pass as shown by more resolvable carbides. This zone was heated slightly above the critical temperature adjacent to the untransformed base metal and progressively higher as an area adjacent to Zone 2 is approached. The area is mostly upper bainite with coagulation of the aggregate beginning and even some fine pearlite in the forward end of this zone. It is a tough, strong, constituent and is not subject to failures of the static or impact type except at very high loading.

The next zone is the torch normalized base metal which was cooled by an air jet in the manufacturing process to produce a slightly hardened rail surface. This structure shown in Fig. 6 (*D*) is a fine pearlite structure with some free ferrite which should exhibit rail-steel properties.

Examination of Section 2 disclosed a sound weld with the heat-affected zone in the base metal decreasing from 0.080 in. on the top of the rail to about 0.035 in. at the base of the groove and start of the root opening. The hardened structure in Fig. 6 (*D*) was shown to extend down into the rail a distance of about $\frac{1}{4}$ in. The inside structure of the rail was an annealed laminated pearlite structure with a few free ferrite segregations visible. The weld metal-base metal interface was irregular except at the root and top of the groove. Section 3 showed a similar heat-affected zone of about 0.035 in. into the base metal at the root opening. The first-pass and base-metal interface was a regular, fairly straight-line type. The weld was sound in the root opening.

The specimens were etched after these examinations of the base metal by a 10% oxalic acid electrolytic etch to determine if there was any carbide precipitation in the weld metal at or parallel to the interface which could produce a plane of weakness in the weldment. The carbides present in the weld metal were well dispersed and normal in number and size. No boundary segregation of carbide was found at the interface. The effects of strain hardening by peening could be observed on the austenitic weld metal shown by some grain distortion and small amounts of ferrite in the austenitic grain boundaries.

WELDING IN THE TOWING BASIN

The following welding tests were conducted in the towing basin. The chairs are imbedded in concrete and are held rigidly. The rails are placed on steel shims about 0.23 in. thick, which are resting on the basin chairs. The rails are bolted down and aligned with wedges following the procedure for unwelded rails now on the basin chairs.

Three rail sections were used in this first weldment; two sections approximately 6 ft. in length and one 22-ft. section were used. The same type joint design was used as before. The two small rails were brought together to make one joint and the large section joined to one end of a small section for the other joint. The method of alignment was the same as before; however, a scribed steel plate was attached to the chair for the purpose of realigning the sag wire in identical positions on the chair after removal of the wire during welding, one being on each end of the rail assembly. A 6-ft. bubble level was used on top of the rail head with two ground and polished $\frac{3}{8}$-in. blocks to obtain the profile data. A 1-ft. bubble level was used to obtain the transverse level readings. Rail gages were placed at the extreme ends of the assembly to read any possible longitudinal movement of the rails. Figure 7 shows some of these instruments. A strain gage was used to measure movement at the joint composed of the two short sections. It was not possible to drill the necessary gage holes at the joint of the long and short rail section so no strain gage measurements were made there. A contact pyrometer was used for temperature measurements.

The rail sections were welded following the same procedure as before. A 25-20 stainless-steel welding electrode was used for the first pass in the second joint, all other passes and procedures were the same as previous procedure. The average contraction along the head of the first joint due to weld metal shrinkage was 0.019 in., while in the second joint it was 0.028 in. The shrinkage in the flange due to contraction of weld metal was 0.020 in. in the first joint, while it was only 0.002 in. in the second.

The long rail section was bolted down at a bolt hole adjacent to the weld and at the bolt hole on the extreme end. The wedges which were placed at these two positions only on the long rail, were so set

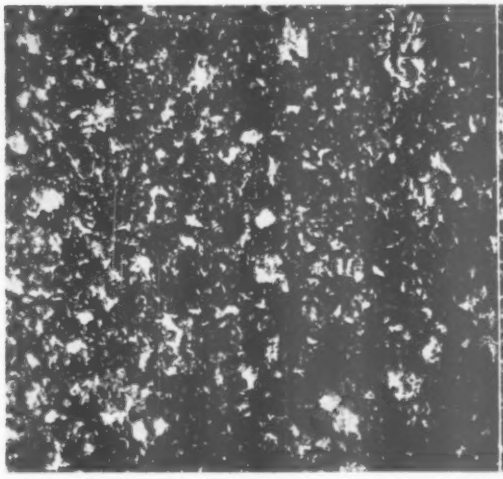


Fig. 6 (C) Showing transition products intermediate between martensite and pearlite formed in Zone 3. Etchant 3% Nital. 500 ×

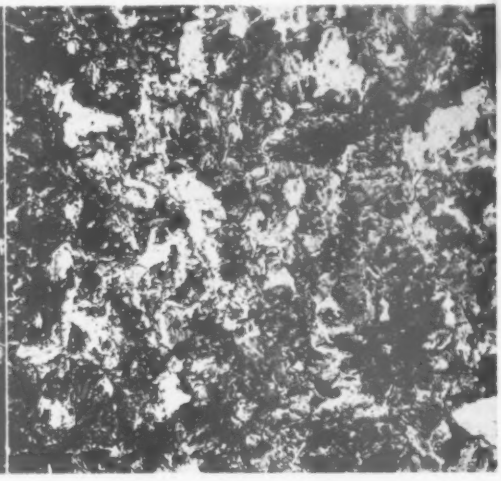


Fig. 6 (D) Showing fine pearlite and some free ferrite in the surface-hardened rail. Etchant 3% Nital. 500 ×

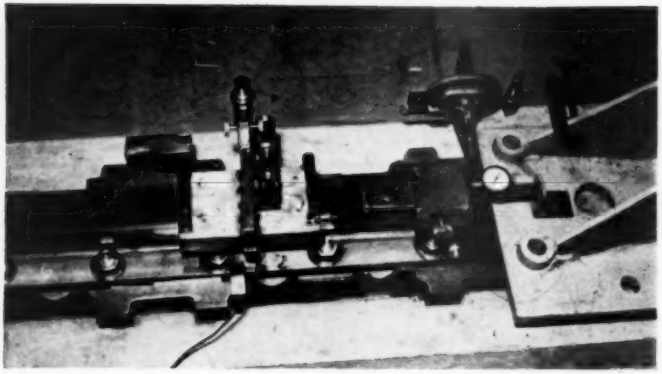


Fig. 7 Instruments used for measuring alignment of welded rails

as to tighten when the rail moved longitudinal during preheating and to loosen upon shrinkage at the joint due to weld-metal deposition. The extreme end of the long rail stretched out 0.030 in. during preheating while at the same time the root opened up from 0.068 to 0.079 in. due to expansion of the shim plate in the joint. The two smaller rail sections were secured tightly by bolts and wedges so as to give the minimum amount of longitudinal and transverse movement. The wedges were placed so as to tighten on preheating and loosen on shrinkage. This joint opened up 0.010 in. on preheating, changing the root opening from 0.065 to 0.075 in.

Sag wire measurements showed the two short sections remained straight except at the joint. The long rail bowed out 0.035 in. on welding at about 1/4 its length from the joint.

The profile of the rail taken by level readings gave a maximum bow upward of 0.006 in. about 1/4 the length of the long rail from the welded joint. Transverse level readings taken across the width of the rail head gave a difference of 0.004 in. at the short-rails welded joint and 0.003 in. at the long-rail joint. Measurements made with an indicator dial gage gave an offset of 0.018 in. along the sides of the rail heads at the long-rail joint and 0.003 in. on top of the head. The two short lengths gave a side offset of 0.030 in. and a top offset of 0.001 in.

Loosening the rail caused a maximum bow of 0.050 in. in the long-rail section, however the rail could be realigned and bolted and wedged straight again. The offset at the joints, both side and top, could not be corrected by realigning, nor could the twist at the joints due to welding be corrected. Having both sections bolted down tight and secured by wedges while making a welded joint gave no apparent advantage along the length of the rail in alignment and was distinctly disadvantageous at the welded joint.

Since a joint made with one rail free to move while the other was fixed rigid seemed to be the most promising method, all subsequent welds were made in this manner. The 1/16-in. steel shim was eliminated. This piece was used in all previous tests as a backing plate for the weld metal being inserted between the rail ends at the joint in a snug fit. It was thought that the expansion of this piece during preheat and restraint exerted by it during weld-metal shrinkage resulted in the offset measured at the joints. A 1/16-in. diameter 25–20 stainless-steel wire was bent to fit the joint at the root opening and crimped to hold it in place. The gap at the joint may be set larger than the wire diameter to allow for closing of the gap during perheat. Methods of placing and aligning the rails and instruments used for the subsequent welds are the same as previous procedure.

Four rail sections were used to obtain three welded joints. One long-rail section approximately 16 ft. in length was welded to a 4-ft. rail section; then this resulting 20-ft. section was welded to another 4-ft. section and this resulting section welded to the next 4-ft. section. This sequence of welding was followed until three welded joints were obtained. The short-rail section in each case was bolted down tight and wedged while the long section was bolted only at one bolt hole at the joint and wedged only at the joint.

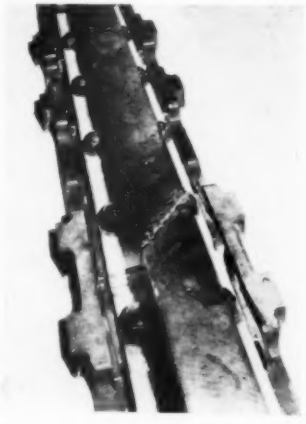


Fig. 8 Finished basin weld before grinding

The wedges were so set that the short fixed rail would tighten up in its wedges on shrinkage of the weld metal in the joints and tend to stay stationary, while the one set of wedges at the joint in the long loose rail would tend to loosen upon shrinkage of the weld metal in the joint, and allow the long free section to draw up as the weld shrinks. A preheat test was made on the first joint to see if any offset occurred in the joint during preheat. The rail joint was heated by one torch at the joint for a period of 7 min. to a temperature of 500° F. in the head and 400° F. in the base. The gap in the head of the rail closed 0.015 in. while the base showed a decrease of 0.011 in. On cooling to room temperature the two thin corners of the miter joint moved out 0.002 in. This joint was then welded using a 25–20 stainless-steel electrode for the first passes in the head and flange, and Frogalloy for all succeeding passes. The weld showed 0.030 total shrinkage in the joint.

The second joint was welded in the same manner as one with two exceptions.

1. Two torches were used for preheating. The head of the rail was covered with thin asbestos cloth and one torch was used on each side of the joint in the web and flange only. The flame never impinged on the head of the rail. The rail head reached the same temperature as the first joint in only 4 min. of heating.

2. Only two passes were made in the base, both with 25–20 stainless steel. The welding procedure in the head was the same as before. Two thousandths more shrinkage occurred in this joint than in the first.

The third joint was an exact duplication of the second in procedure except for using a transite hood to cover the railhead during preheat. The temperature reached 600° F. in the base in only 3 min. Shrinkage of about 0.025 was measured in the joint.

The welded rail was aligned and tightened on the basin and the offset at the welded joints measured. Transverse level readings were made with a 1-ft. length, 0.00025-scale division level to detect possible twist. The same measurements were made with the rail loosened. The welds were later ground down to rail level and the sliding scope and sag wire used to measure offset. Data is given in Table 2.

Micrometer readings were made at the joint of the rail sections to ascertain whether the offset was due to movement of the two rail sections being welded, or the thin angle being pulled in by the weld metal. The micrometer readings show the thin section to be in the first two welds

Table 2—Offset Measured at Welded Joints

		Indicator bar, in.		*Sag wire levels, in.*		
		Side	*Top*	*Side*	*Top*	*Twist*
As-welded	Joint 1	0.004	−0.001	0.004	0.001	−0.001
As-welded	Joint 2	0.001	−0.001	0.001	−0.001	None
As-welded	Joint 3	0.003	−0.001	0.002	−0.001	None
Loosened	Joint 1	0.007	0.002	0.007	0.002	+0.001
Loosened	Joint 2	0.003	−0.001	0.003	0.001	None
Loosened	Joint 3	0.006	+0.001	0.004	0.001	None

and out in the third. The offset was due to this movement of the thin corners rather than rail movement. The effect of preheat on alignment is almost nonexistent when two torches are used heating equally from both sides. Using one torch makes it more difficult to obtain equalized heating effect at the joint, making it possible for offset to be present before depositing the weld metal.

This section containing the three welds was cut and prepared for two more welded joints. Design, alignment, etc., were identical with the preceding procedures except as noted. The first weld was made resulting in a longitudinal shrinkage of about 0.028 in. as measured in the joint. The second weld was made using no preheat. The first pass was made from the top down the side of the railhead on both sides. Then both sides were built up alternately until almost level with the side rail-head surface. Then a pass was made in the root across the top of the rail head, and in the base on both sides. The top-head groove was then filled flush to the top-rail surface. The second pass was then made in the base, and the top and side welds in the head overlayed. All passes in the base were made with 25–20 stainless-steel electrode while only the root passes in the head were of 25–20 stainless-steel electrode; all others being Frogalloy. All passes were peened except the overlay passes in the head. The rail temperature at the joint was about 65° F. before welding. The maximum temperature on completion of the last overlay pass was 250° F. adjacent to the weld. The weld was then postheated using two torches to a temperature of 400° F. in order to temper any possible martensite that may have been present at the weld metal-rail interface. A total longitudinal shrinkage of about 0.008 was measured in the joint on cooling to room temperature. Table 3 gives the data obtained on these two welds.

The data on these two welds is very little different from that of the previous test showing the thin corners were again pulled in by the shrinkage of the weld metal. In making Joint 5 cold, the exact position of the corners before the welding could be measured, and since no preheating was used, which could disturb the position of these corners, the dimensions just prior to weld metal deposition could be definitely established. In this way that part of the magnitude of the movement of the thin section for which the weld-metal shrinkage was responsible could be measured.

Micrometer and other measurements taken before and after welding show the transverse weld-metal shrinkage pulled the thin corners in 0.007 in. in the second welded joint.

Two joints were prepared for welding from two short rail lengths and one long one. The first joint was a miter joint which was prepared for welding as in all previous tests with one exception. The sharp miter corner on one of the rail sections of the joint was set out approximately 0.011 in. by torch heating the thin corner section to a temperature of about 800° F. The heating was done from the inside thus preventing the flame from impinging directly on the outer rail surface. The corner was moved out by a peening tool with compressed air hammer. A butt joint was prepared using a V-groove, with 45° included angle in the top of the rail head to a depth of 1/4 in. and a 70° V-joint with a depth of 1/8 in. in the sides of the head. Nominal root openings of 1/16 in. were used. A 90° V-groove of 1/4-in. depth was used in the base. These two joints were both made with the same welding technique. Temperature was maintained at 450° F. during welding. The order of passes used is shown in Fig. 9 using a 25–20 stainless-steel electrode for all base passes and 25–20 electrode for the root pass only in the head, all others being Frogalloy.

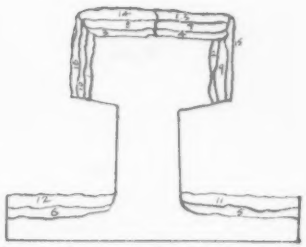


Fig. 9 Sequence of welding passes in welded rail joint

Passes	Rod
1-2-3-4-5-6	5/32 25–20
7-8-9-10	5/32 Frogalloy
11-12	1/8 25–20
13-14-15-16	1/8 Frogalloy

The gap was set at 0.082 in. for both joints measured longitudinally before preheating. The thin acute angle section on the miter joint, which had not been previously peened out, received an overlay of weld metal on the side head surface from the original weld metal-rail boundary back along the rail a distance of approximately 1/2 in.

Sag wire and levels measurements were used before and after welding. The present thin miter corner showed 0.009 in. out, while the other thin corner was 0.004 in. out before welding as measured by indicator bar measurements. The shrinkage in the miter joint was 0.030 in. The sharp corner which was preset out before welding was pulled in as much as in previous tests by the weld metal shrinkage. The other thin section was pulled in slightly less than 0.002 in. at a position just adjacent to the overlayed weld metal. The shrinkage in the 90° butt weld was 0.031. A wedge between the "free" rail base and chair stud was accidentally loosened while welding so the butt joint in this weldment was a partially free joint. This 90° butt type joint gives satisfactory alignment results and greatly facilitates preparation, welding and alignment control.

This welded assembly was cut into a 4-ft. length and about 0.002 in. was removed from the top of the head and about 0.003 in. from each side. The machined assembly was bolted down on the batter test-bed plate with the overlayed side of the miter joint and one side of the butt joint being placed to accommodate the railroad driver wheel for a rail head batter test of the two joints.

The results[2] of this test using a 20,000-lb. load for one-half million cycles gave less than 0.001 in. batter in the heat-affected zones adjacent to the edge of the weld; cracks appeared at about the halfway point of testing in the miter joint and propagated progressively until completion of test; maximum batter adjacent to largest crack was 0.002 in.; no cracks or

Table 3—Offset Measured at Welded Joints

	Indicator bar, in.		*Micrometer, side, in.*	*Levels, top, in.*	*Twist, in.*
	Side	*Top*			
Joint 4					
North	0.005	−0.001	0.005	+0.001	0.001
South	0.002	.....	0.003	.....	.....
Joint 5					
North	...	0.001	0.003	0.001	−0.001
South	...	.....	0.005	.....	.....

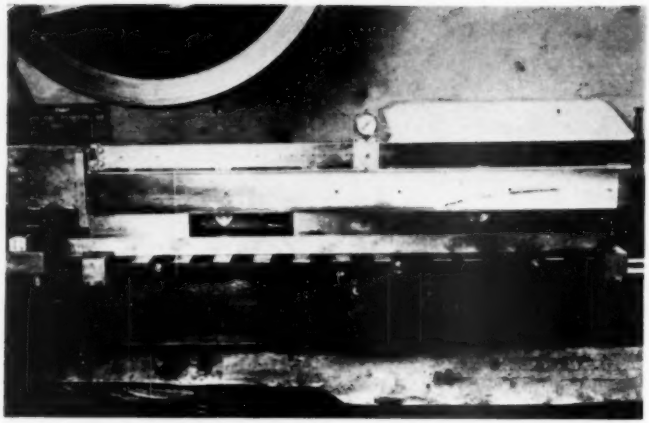


Fig. 10 Photograph of rail in batter test machine

Fig. 11 Micrograph of crack in weld metal of miter joint developed during batter test

appreciable batter occurred in the weld metal of the butt joint. This test simulated 100% overload of the maximum load that is expected to occur in operation on the towing basin, for a period of approximately 25 yr. normal use.

The rail section on completion of tests was tested for hardness on the rolled and unrolled sides and top head surfaces. The unrolled butt-weld metal averaged about 26 Rockwell C with a small zone adjacent to the rail having various hardnesses from 29 to 44 Rockwell C. The rolled butt weld metal averaged about 30 Rockwell C and a larger transition zone adjacent to the rail steel having hardness ranging from 32 to 44 Rockwell C maximum. The hardnesses in the miter unrolled section were similar to the butt weldment. The hardnesses in the rolled miter section averaged about 30 Rockwell C. The maximum hardness in the weld metal adjacent to the rail steel was 39 Rockwell C. The hardness adjacent to the crack in the center of the weld metal averaged about 26 Rockwell C. The hardness of the weld metal increased progressively as the overlay junction was approached, being 45 Rockwell C at the juncture. The hardnesses in the weld-metal overlay varied greatly, from 32 to 48 while at the juncture of the rail steel and overlay hardnesses of 54 to 60 Rockwell C were recorded. The cracks in the weld-metal overlay seemed to be in the softest weld metal. This would indicate a fatigue failure in an area of minimum strain hardening having he lower endurance limit, rather than brittle fracturing in harder zones. Micrographs such as Fig. 11 show the crack propagating in the softer weld metal following inclusions which are probably acting as stress raisers.

The heat-affected zone in the butt weld as shown in Fig. 12 had practically the same constituents and dimensions as the original miter joint shown in Fig. 5.

ACKNOWLEDGMENTS

The author wishes to acknowledge the aid and suggestions given during various phases of the investigation by Commander L. W. Shallenburg, former Industrial Officer, Taylor Model Basin, and V. Miller, Mechanical Engineer, Taylor Model Basin.

References

1. Alleman, N. J., University of Illinois Report on Rolling Tests of Two Types of Rail Joint, No. 15446013, April 1946, p. 23.
2. Jensen, R. S., University of Illinois Report on Rolling Tests on Welded Rail Joints, October 1948, p. 17.

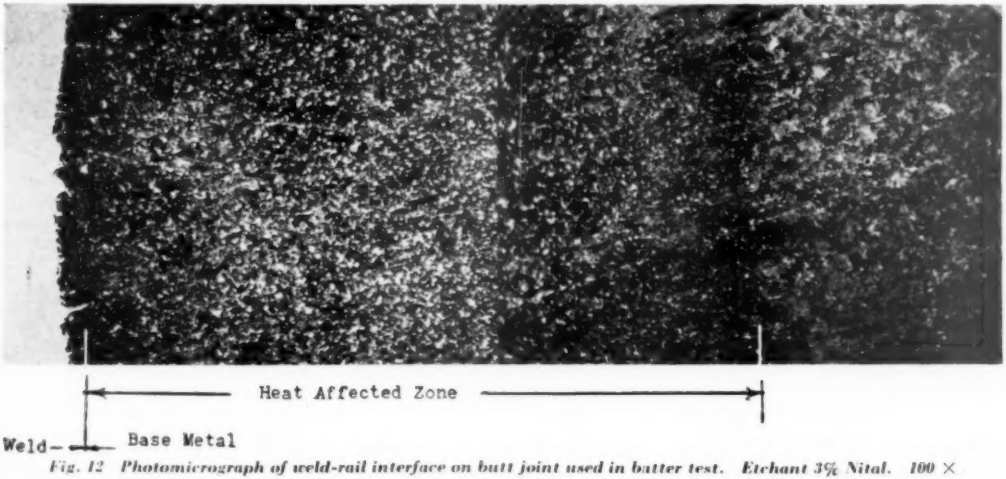


Fig. 12 Photomicrograph of weld-rail interface on butt joint used in batter test. Etchant 3% Nital. 100 ×

Metallurgical Aspects of Welding Mild Steel

Factors governing the selection of electrode coverings are a judicious compromise between weld metal properties and operating characteristics. Some of these factors are briefly described in this article

by Nils Christensen

THE problem of choosing the right electrode for a given welding job will often be one of striking the right balance between quality requirements and factors affecting welding economy (welding speed, operating characteristics of electrode, etc.). Frequently, a medium quality electrode will be preferred even for welding highly stressed construction, as the very highest weld quality is seldom obtained without sacrifice of desirable welding properties. Consequently, there will always be demand for several electrode quality grades. Thus, according to Barnett[1] the consumption of E6012 electrodes in the United States has surpassed that of the E6010 type, although the former give a weld of definitely lower quality. In the Scandinavian countries, the different types of electrodes have been classified in groups by Sjöman[2] and other authors[3–6] according to the composition of their coatings.

In this paper the electrode types will be termed by their A.W.S. code numbers. Two types not standardized by the A.W.S. will be referred to as "standard electrode" and "oxidizing electrode," respectively, the former being an all-position parallel to E6020–E6030 and the latter a mild steel wire covered with an iron oxide-feldspar flux. The European "standard electrodes" are by far the most universally used types in the Scandinavian countries.

A metallurgical classification of different electrode types on the basis of conventional chemical analyses of their deposit does not yield sufficient information on the weld quality. Generally it will not be possible to predict the exact value even of the weld metal's tensile strength from its content of carbon, manganese, silicon, sulphur and phosphorus. An estimation of the behaviour of the material in a triaxial stress condition, or of its crack sensitivity, would be far more difficult. Though the amount of experimental data regarding relation of weld metal composition to weld metal properties is steadily increasing, it will probably not be possible to reach much farther on this way. However, a consideration of weld metal composition together with composition of the corresponding slag appears to be a sounder basis, because the slag composition can give information as to the method of weld metal manufacture.

Experience from steel-making practice has been condensed in the sentence "Make the slag, and the steel will take care of itself." More precisely, this experience may be stated in terms of chemical equilibrium laws. It has been proved by experiments carried out independently in the United States[7] and in Norway[8] that, with some reservations, equilibrium conditions may be assumed to exist between the molten metal and slag during the last stage in the arc-welding process. Figure 1 shows the relation between manganese content of the deposit and the ratio MnO % to FeO % (by weight) in the slag phase. The equilibrium constant for the reaction

$$Mn_{(\text{in weld})} + FeO_{(\text{slag-weld})} = MnO_{(\text{slag-weld})} + Fe_{(l)}$$

$$K_{Mn} = \frac{(MnO\ \%)}{(FeO\ \%)\ [Mn\ \%]}$$

is calculated to 2.8 from the slope of the straight line in

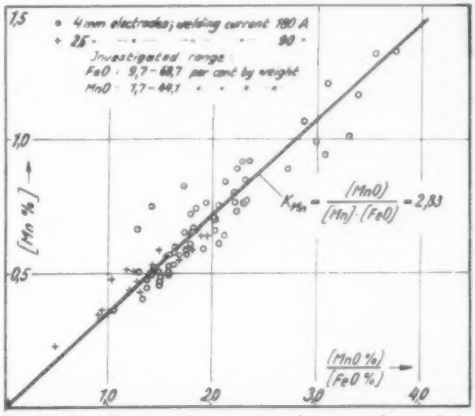


Fig. 1 Distribution of manganese between slag and deposit

Nils Christensen is with The Norwegian Institute of Technology.
Part of this paper was read at the Scandinavian Welding Congress in Copenhagen, September 1948.

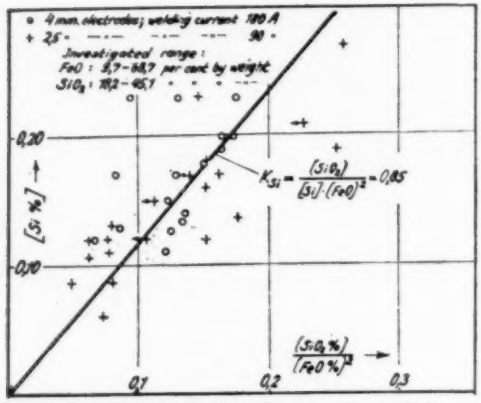


Fig. 2 Distribution of silicon between slag and deposit

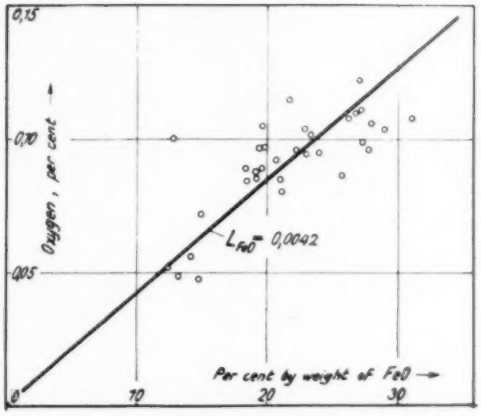


Fig. 3 Oxygen distribution coefficient calculated from measurements by Babcock[7]

Fig. 1. Figure 2 shows a corresponding relation between silicon content of the steel bath and SiO_2 and FeO percentages in the slag. These figures refer mainly to heavily coated "standard electrodes" of European type. In Fig. 3 is shown the relation between total oxygen content of the deposit and FeO content of the slag, calculated from Babcock's experiments with E6010, E6012 and E6020–E6030 electrodes.[8]

From the numerical values of these equilibrium constants may be calculated—an equilibrium temperature about 1800° C. Obviously, steel and slag composition does not change much during cooling and solidification. However, this simple relationship does not apply to carbon dissolved in the bath. Nor will it be valid for every kind of welding slag because the dissolved oxides FeO, MnO and SiO_2, will tend to form chemical compounds with each other and with the other components of the slag (CaO, MgO, TiO_2, etc.). Considering, for instance, some fixed percentage of FeO, its activity will be smaller in an acid slag than in one of the lime type. The reverse will be true in case of SiO_2 itself.

Welding slags formed by commercial electrodes are too complicated to permit exact calculation of the activity coefficients of FeO, MnO and SiO_2. An approximate estimation may be made by application of data from Körber and Oelsen.[9, 10] Chipman's method,[11] which is based on assumption of slightly dissociated compounds, appears to be widely used in the United States. In this paper it has been found more convenient to express all concentrations as percentages by weight, as this method permits generalization for related slag types without stating the exact composition in each case. Welding slags from European standard electrodes, E6020–E6030, E6010–E6011 and oxidizing electrodes will be compared with the saturated acid system Fe/FeO–MnO–SiO_2/solid SiO_2, and slag from lime-coated electrodes with the pure basic system Fe/FeO–MnO. It should be remembered, however, that these systems are borderline cases which probably do not represent the actual conditions in any welding slag.

The oxygen distribution coefficient L_{FeO} in the pure basic system has been measured in the temperature range 1600–1900° C. The acid saturated system has been investigated up to the melting point of SiO_2. Assuming that the temperature coefficient of L_{FeO} in the acid system will not change its value much on heating, the distribution coefficients may be represented by the equations:[9, 10]

$$L_a = 0.85 \times 10^{-5} \times t - 0.00114_5 \text{ (acid system)}$$

$$L_b = 1.31 \times 10^{-5} \times t - 0.0177 \text{ (basic system)}$$

When these two different slags are in equilibrium with the same steel bath, the FeO activity must be equal in both. Hence:

$$(\gamma_{FeO})_a = \frac{L_a}{L_b} \cdot (\gamma_{FeO})_b$$

where indexes a and b refer to acid and basic media. If the basic system may be treated as ideal, then

$$(\gamma_{FeO})_b = (\gamma_{MnO})_b = 1$$

$(K_{Mn})_b = K'_{Mn}$ = the true (thermodynamic) equilibrium constant

In the acid system at temperatures above 1700° C the activity coefficient γ_{SiO_2} presumably will not differ much from unity when γ_{SiO_2} is chosen = 1 in the saturated system.

These assumptions lead to the equations

$$(\gamma_{FeO})_a = \frac{L_a}{L_b}$$

$$K'_{Mn} = (K_{Mn})_b$$

$$(\gamma_{MnO})_a = \frac{(K_{Mn})_b}{(K_{Mn})_a} (\gamma_{FeO})_a$$

$$K'_{Si} = (K_{Si})_a \frac{1}{(\gamma_{FeO})_a^2} < (K_{Si})_b$$

Substituting numerical values for L, K_{Mn} and K_{Si} from Körber and Oelsen's papers, one obtains the figures in Table 1. Data for calculation of the silica activity in lime slags are not available. However, the activity co-

Table 1—Activity Coefficients and True Equilibrium Constants

Temp., ° C.	1500	1600	1700	1800	1900	2000
$(L_{FeO})_a$	0.0013_5	0.0021_5	0.0030_5	0.0038_5	0.0047_5	0.0055^b
$(L_{FeO})_b$	0.0019_8	0.0032_5	0.0046_9	0.0059_0	0.0072_6	0.0085_0
$(\gamma_{FeO})_a$	0.66	0.66	0.65	0.65	0.65	0.65
$(K_{Mn})_a$	20.6	11.9_5	7.20	4.62	3.07	2.12
$(K_{Mn})_b$	3.13	2.0_3	1.38	0.97_6	0.70_3	0.52_8
$(\gamma_{MnO})_a$	0.10	0.11	0.13	0.14	0.15	0.16
$(K_{Si})_a$	23.2	6.16	1.87	0.63_7	0.23_9	0.98_7
K'_{Si}	53	14	4.4	1.5	0.56	0.23

$(\gamma_{SiO_2})_a$ is chosen equal to unity. $(\gamma_{SiO_2})_b = 1$

efficient must be appreciably lower than is the case in acid slags (below unity when activity is defined as identical to weight per cent concentration in the acid system).

An application of the preceding equations is shown in Table 2, giving the equilibrium constants for various kinds of commercial electrodes. The corrected constants K'_{Mn} and K'_{Si} have been calculated by means of activity coefficients at 1800° C (Table 1), referring to SiO_2-saturated and SiO_2-free systems, respectively. It must be expected to combine to a greater extent with silica than with ferrous oxide. The SiO_2 constant of E6013 electrode has a higher value than expected, corresponding formally to a lower reaction temperature. It will not be discussed here whether the cause might be sought in different activity coefficients in presence of titanic acid, or perhaps these fluid rutile slags might permit chemical reaction down to lower temperatures. Anyhow, E6012 and E6013 do not behave like "standard electrodes" in another respect also. The carbon

Table 2—Metallurgical Data for Different Types of Commercial Electrodes

Electrode No.	Electrode Type	Manufacturer	FeO, %	MnO, %	SiO_2, %	Mn, %	Si, %	K_{Mn}	K_{Si}	K'_{Mn}	K'_{Si}
1	Standard	Eur.	16.6	21.2	40.3	0.49	0.14	2.6_1	1.0	>0.56	2.4
2	Standard	Eur.	10.6	16.6	40.8	0.54	0.35	2.90	1.0	>0.62	2.4
3	E6020	Am.	14.2	24.0	40.3	0.63	0.13	2.6_8	1.5	>0.58	3.5
4	Oxidizing	Eur.	69.8	1.80	25.2	0.01	<0.009	2.6	>0.6	>0.56	>1.4
5	E6011	Am.	9.5	8.6	30.5	0.36	0.28	2.5_1	1.2	>0.54	2.8
6	E6015	Eur.	2.8	2.31	20.3	0.69	0.57	1.2	4.6	<1.2	<4.6
7	E6015	Am.	3.31	2.23	17.9	0.64	0.28	1.1	5.8	<1.1	<5.8
8	E7015	Eur.	2.43	4.4_4	20.9	1.67	0.77	1.1	4.6	<1.1	<4.6
9	E6013	Eur.	6.4	11.9	26.7	0.50	0.38	3.73	1.7	>0.80	4.0
10	E6013	Am.	6.9	7.6	28.5	0.30	0.28	3.68	2.1	>0.79	4.9

has already been mentioned that these systems represent borderline cases. Therefore, the true value of the constants probably will be somewhere between K and K', as indicated in Table 2 by $<$ or $>$ for all manganese constants and for the silicon constants of the lime slags. From the values of K'_{Mn} it may be deducted that in all cases investigated here the manganese deoxidizing reaction probably leads to the same final state corresponding to equilibrium at about 1800° C. It is possible that this will be true also with silicon deoxidation. But in this case it is rather difficult to decide whether the applied correction has been too small or too large, as γ_{SiO_2} in unsaturated acid systems is not known. However, the "true" silicon constant applying to basic slags is certainly too large, as lime, magnesia and fluorspar and oxygen contents of standard electrode welds do not indicate any reaction to CO on solidification, while composition of slag and deposit from E6013 electrodes show that this reaction has occurred, leading close to equilibrium values of [C] and [O] at 1800–1900° C. Perhaps this reaction may contribute to the well-known porosity in multiple-pass welds made with E6013 electrodes.

In Fig. 4, constructed from measurements by Babcock,[8] the reciprocal carbon content has been plotted vs. the total oxygen content in weld metal from E6010, E6020–E6030 and E6012–E6013 electrodes. The last ones marked with F, tend to reach the equilibrium line. Comparison with Fig. 5 shows clearly the difference between these electrodes and heavily coated "standard electrodes" of European type. The experimental values

Table 3—Notch Impact Values for Butt Welds Made with Electrodes Shown in Table 2

Electrode No.	Electrode Type	Manufacturer	% FeO in slag	Notch impact value (Charpy) mkg./cm.² Testing temp., +15° C.		Testing temp., −20° C.	
1	Standard	Eur.	16.6	7.6_5		6.6_1	7.1_2
2	Standard	Eur.	10.6	7.4_3	(5.4_2)*	8.0_3	...
3	E6020	Am.	14.2	8.4_8	9.1_2	8.4_2	
4	Oxidizing	Eur.	69.8	4.0_1	3.6_8	3.7_1	(3.1_4)
5	E6011	Am.	9.5	7.1_6	(5.5_2)	7.1_2	...
6	E6015	Eur.	2.80	14.8_7	14.8_7	14.9_6	...
7	E6015	Am.	3.31	14.4_5	14.9_6	14.1_7	14.5_3
8	E7015	Eur.	2.43	12.4_8	12.3_5	11.0_5	11.6_8
9	E6013	Eur.	6.4	8.6	(6.3_0)	7.1_8	7.2_5
10	E6013	Am.	6.9	(6.5)	(6.5)	8.9_4	(5.9_0)

* Numbers in parentheses refer to specimens showing blowholes or inclusions in the fracture.

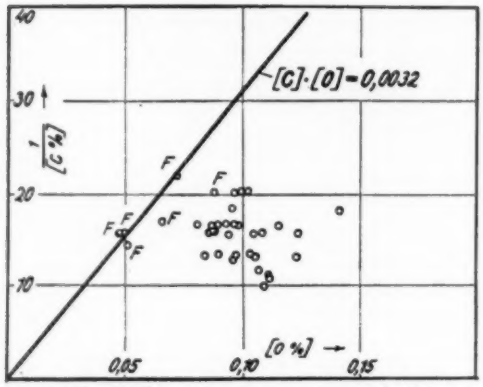


Fig. 4 [C] and [O] according to measurements by Babcock[7]

are scattered at random, but every point is well below the equilibrium line at 1900° C.

As will be noted from the examples cited above, welding slags from commercial electrodes may contain ferrous oxide in the range from about 2 to about 70% by weight. Parallel to this variation in FeO content of the slag, the oxygen content of the corresponding weld metal will vary from about 0.02 to about 0.4% O. Although oxygen is known to impart undesirable properties to steel, its determination is usually omitted in conventional chemical analysis because the analysis procedure is rather complicated and expensive. A determination of total iron oxide (Σ FeO) in the corresponding slag seems to be a far more convenient and rapid method. In addition, knowledge of the FeO content of the slag will supply valuable information on the general electrode characteristics to an experienced welding metallurgist.

Among the undesirable properties of oxygen-bearing steel may be mentioned a low notch impact value. This feature is illustrated in Table 3, giving Charpy notch impact values of butt welds made with the electrodes

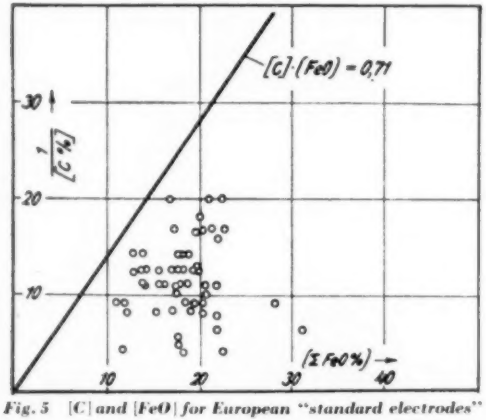


Fig. 5 [C] and [FeO] for European "standard electrodes"

shown in Table 2. All welds have been made with maximum welding current as stated by the manufacturers, and specimens have been cut and tested without any preceding heat treatment. It will be noted that the lime coated Exx15 electrodes depart from the other ones not only by their high impact value, but also in the sense of insignificant scattering of the experimental data. The E6011 and E6013 types exhibit a rather high percentage of inclusions and porosity, indicated by parentheses in Table 3. It is believed that these defects are due chiefly to somewhat too high current values given by the manufacturers. None of the electrodes tested showed any noticeable reduction of impact value when tested at −20° C. In Fig. 6, notch impact values are plotted vs. oxidizing power of slag. In spite of a rather large scattering, it may be concluded that a total ferrous oxide percentage below 5% would be necessary to obtain impact values higher than 12 mkg./cm.².

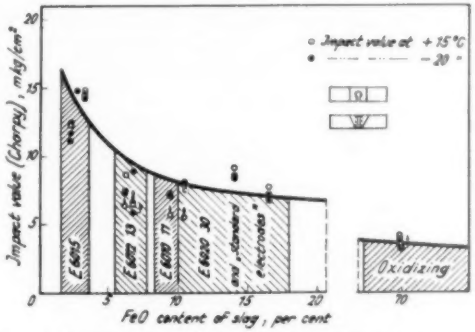


Fig. 6 Impact values of deposits from electrodes shown in Table 2

However, the scattering itself proves that a low FeO content would not be a sufficient condition, as even the best material would be spoiled by discontinuities like gas pockets, fissures or inclusions. For a complete study it would also be necessary to consider the effect of nitrogen and hydrogen.

Oxidizing electrodes are now being used only to a limited extent. An oxidized weld has a low tensile strength and impact data inferior to those of the base metal. Testing according to H. Schnadt[12] would probably indicate poor resistivity in a triaxial stress condition. It is interesting therefore to note that the oxidizing electrodes have shown an unexpected small crack sensitivity according to E. Helin[13] and L. Reeve.[14]

Whereas oxygen in weld metal may be partly derived from the coating, air is the only source of nitrogen. It has been shown that the oxygen content may be controlled by a suitable welding slag even without any deoxidizing agent present (as in the Unionmelt process). However, the only means of keeping nitrogen out of the weld metal pool is an efficient gas or slag shielding. As modern heavily coated electrodes usually have a well-shielded arc, the influence of nitrogen will often be overshadowed by other factors affecting weld metal

quality. Thus, E6012 and E6013 give a low nitrogen deposit, but one which is only of medium quality.

Hydrogen is known to cause weld metal brittleness and under-bead cracks in high tensile steels. Molten steel can keep in solution about 0.003% atomic hydrogen at 1600° C, the exact amount depending on the partial pressure of hydrogen. On cooling, the hydrogen solubility will decrease, and the excess may be excluded as H_2-gas. Such gas evolution in the solidification range will cause weld metal porosity (especially well known from arc-welding light metals with moist electrodes). As the hydrogen atoms are very small, they will diffuse out of the solid weld on storing. However, part of them will encounter discontinuities on their way. In such places molecular hydrogen or water vapor will collect under a very high pressure. According to Zapffe and Sims[15] this pressure may exceed 10,000 atm. From the bath, hydrogen will be transferred to the base metal, which will usually be in the austenitic state at a small distance from the weld metal pool. If martensite formation occurs, molecular hydrogen will precipitate from the supersaturated solution and cause cracks.

There are, however, details which at present are not fully understood. Thus, Flanigan[16] states that acid pickling embrittlement occurs at hydrogen percentages well below those found in ordinary arc welds of fair quality. Reeve[14] distinguishes between dissolved atomic hydrogen and nondiffusable hydrogen (H_2 or H_2O), the former being far more dangerous.

Even though we are unable to explain the mechanism of hydrogen embrittlement, it may safely be stated that a low hydrogen percentage will reduce the risk of embrittlement. Mallett and Rieppel[17] have shown that the high resistivity to under-bead cracks of lime-coated electrodes is mainly due to a low hydrogen content in their deposits. However, they will not deliver low hydrogen deposits unless the coating be completely dry. As lime-coated electrodes are known to be far more sensible to moisture than are other types, it would be of interest to obtain some kind of quantitative information on this point.

Reeve[14] has calculated the equilibrium between dissolved hydrogen and oxygen in molten steel. He finds that the hydrogen content is chiefly governed by the hydrogen partial pressure, being nearly independent of the oxygen content of the bath. In Fig. 7 is shown the result of a similar calculation, giving hydrogen content as function of quantities more readily obtained by direct measurement. The curves have been constructed by means of the Sievert formula

$$[\mathrm{H}] = K_{\mathrm{H}} \sqrt{\frac{K\ p_w}{K + \gamma_{\mathrm{FeO}}\ (\mathrm{FeO}\ \%)}}$$

where

$$K = \frac{p\mathrm{H}_2}{p\mathrm{H}_2\mathrm{O}}\ \gamma_{\mathrm{FeO}}\ (\mathrm{FeO},\ \%)$$

and

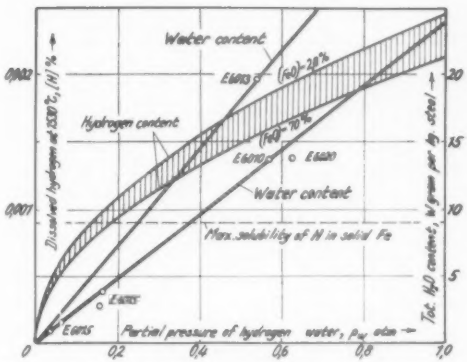


Fig. 7 Hydrogen solubility at 1530° C. vs. partial pressure and moisture

$$K_H = \frac{[\mathrm{H}]}{p\mathrm{H}_2}$$

Numerical values of the constants K and K_H have been computed from Chipman's[11] table of free energies at 1600° C., and that of γ_{FeO} from Table 1. The left ordinate axis shows weight per cent hydrogen as function of partial pressure in the arc atmosphere of hydrogen + water vapor, p_w. The right ordinate axis is graduated in total water content w grams per kilogram core wire, organic hydrogen being added as H_2O to the moisture and combined water of the coating. The points in the plot which have been calculated from measurements made by Mallett and Rieppel,[17] indicate proportionality between p_w and w. Consider as an example a lime-coated E6015 electrode containing 2 gm. total H_2O per kilogram core wire. A horizontal line at 2 gm./kg. will intersect the E6015 curve at a (H_2 + H_2O)-pressure of about 0.09 atm., corresponding to about 0.0007% dissolved hydrogen in equilibrium with a slag of the lime type (2% FeO). This hydrogen content is seen to fall below the dotted line at 0.0009% H indicating maximal solubility of hydrogen in γ iron according to H. Schenk[18]. It will be noted that E6020, E6010–E6011 and E6012–E6013 electrodes will give, either a deposit which is supersaturated with hydrogen, or one which is porous. The analyses given by Mallett and Rieppel as well as investigations by Helin[19] and Sloman and co-workers[20] indicate that the latter case will be the usual one. Furthermore, it may be deduced from Fig. 7 that addition of water will do more harm in an E6015 than in other types of coating. For instance, a weld made with E6010 electrodes will be supersaturated even before addition of extra water. Besides, owing to the slight slope of the [H]-curve in the p_w-range of E6010 electrodes, a rather large quantity of water would be necessary to increase [H] to any considerable extent. In complete agreement with these deductions, E6010 electrodes are known to work especially well with a certain amount of moisture in the coating. An excess of moisture in an E6015 coating, however, is likely to cause porosity because hydrogen

supersaturation in E6015—as will be shown later—will usually be released on solidification. From Fig. 7, a total water content of about 4 gm. H_2O/kg. steel is seen to produce hydrogen exceeding the saturation value 0.0009% H. For this reason, the manufacturers' directions for storing Exx15 electrodes should be closely followed.

Chemical equilibrium between slag, metal and gas leads to a relation between differential water addition and hydrogen content similar to that given by van den Blink.[21] If an increase in FeO content may be left out of consideration, the equilibrium value of [H] will depend on p_w as shown in Fig. 7. The relationship shown in this diagram may be corrected when the buffering action of the slag is small:

Disregarding deviation from ideality in the slag phase, the relative increment in hydrogen content per mole H_2O added

$$\frac{dln[H]}{dn} = \frac{\partial ln[H]}{\partial pw}\,\frac{dpw}{dn} + \frac{\partial ln[H]}{\partial (FeO)}\,\frac{d(FeO)}{dn}$$

may be written:

$$\frac{dln[H]}{dn} = \frac{1}{2n_w} - \frac{1}{2n_g} - \frac{71.8\,[100 - (FeO)]}{2Q_s[K + (FeO)]}\,\frac{dn_{FeO}}{dn}$$

where

n_g = gram molecules gas per kilogram steel
n_w = gram molecules total water per kilogram steel
n_{FeO} = gram molecules FeO per kilogram steel
Q_s = grams slag per kilogram steel

Substituting numerical values from Mallett and Rieppel[17] for E6010 electrodes, viz.,

n_g = 2.8 moles per kilogram steel
n_w = 1.6 moles per kilogram steel
Q_s = 90 grams per kilogram steel
(FeO) = 10% (Table 2),

and

K = 120 at 1530° C[11]

one obtains

$$100\,\frac{dln[H]}{dn} = 13 - 27\,\frac{dn_{FeO}}{dn} = -6\%$$

when $\frac{dn_{FeO}}{dn}$ is taken equal to $\frac{p_H}{p_w} = 0.7$.

Thus in this case the hydrogen content decreases on water addition, as would be expected from van den Blink's formula.

If hydrogen supersaturation be released during the solidification period, a porous weld will result. This is what happens when a high sulphur or/and silicon material is being welded with standard electrodes. The true nature of this porosity-yielding process is not known. Regarding the base metal silicon content, Zeyen[22] has observed weld metal porosity when large amounts of acid silicate slags were present in the base metal. It appears to be a reasonable assumption then that these acid slag inclusions may execute a catalytic action on the formation of hydrogen bubbles, as they will usually be of a very irregular shape with many "active" points.

When silicon-bearing steels are welded with oxidizing electrodes, weld metal porosity is usually not observed. Probably, the catalytic action of the base metal inclusions is greatly reduced in this case by the large quantities of liquid ferrous oxide separating out of the weld metal and converting them into a less active spherical shape.

Even when the base metal contains no slag inclusions at all, pickup of elementary silicon may cause weld metal porosity, as solid "active" deoxidation products may be rejected from the melt during the solidification period. It should be remembered that deoxidation slags will never contain the fluxing agents always present in the welding slag itself, but will consist merely of the components FeO, MnO and SiO_2. The ratio of these oxides may be calculated from data given in Table 1, or the slag composition may be estimated from Körber and Oelsen's diagram (Fig. 8). An inspection of this diagram together with the data plotted from Table 2 reveals that the deposit from one of the lime-coated electrodes (No. 6, Table 2) will contain small amounts of pure SiO_2, separated out during the first period of solidification. Consequently, any excess of hydrogen (derived from a moist coating) would be likely to cause blowholes, in full agreement with experimental evidence.

Extraordinarily high welding currents will increase the quantity of deoxidation slags because overloading will increase the temperature of the bath and thereby the solubility of oxygen. Indeed, welding currents exceeding the normal value is often observed to cause porosity, especially in the case of standard electrodes giving a high-silicon deposit. Possibly, inclusions of irregular shape will also release the latent tendency of reaction between oxygen and carbon on solidification. It has already been mentioned that the product [C%] [O%] is well above the equilibrium value in most of the European "standard-electrode" deposits.

It has proved difficult to explain blowhole formation in sulphur-contaminated steel from thermodynamic considerations. However, catalytic action of manganese sulphide may possibly play a role. According to Rollason and Bishop,[23] a steel bath containing less than 0.3% Mn will not reject manganese sulphide on solidification when the oxygen and sulphur contents are of the usual order of magnitude. Welds made with oxidizing electrodes contain very much oxygen, only traces of Mn and medium quantities of sulphur. Here an eutectic mixture of FeS and FeO will separate *after complete solidification* of the metal. Thus, there will be no sulphide nuclei present to catalyze formation of hydrogen bubbles. Regarding the lime-coated electrodes, sulphur porosity would not be expected at all, since neither hydrogen nor sulphur are present in sufficient amounts.

One of the worst drawbacks of standard electrodes as compared with lime-coated ones is their tendency to produce autocracks, especially in fillet welds made on high-tensile steels. Helin[13] states that autocracks originate at active points of irregularly shaped slag inclu-

sions. Such inclusions of acid nature, combined with the flat or concave weld contour obtained with these electrodes are regarded as main sources of autocracks. Gas pockets, and the spherical inclusions formed by oxidizing electrodes, do not produce the stress concentrations necessary for starting cracks. However, as the crack sensitivity of a given electrode will depend more pronouncedly on the base metal's carbon than on its silicon content, it seems reasonable to make chemical reactions involving carbon responsible for starting cracks at points of high stress concentration. Thus, acid slag inclusions leading to cracks in a killed medium-carbon steel will not produce any cracks in a low-carbon steel containing the same amount of total silicon. Besides, if the action of carbon be left out of consideration, it would be difficult to understand why solid SiO_2 separating out of weld metal from lime-coated electrodes should not cause any tendency to cracks.

Regarding cracks occurring at temperatures above 1200° C, the only possible gas-producing reaction would consist in formation of CO from dissolved C and O. Cracks started by evolution of carbon monoxide would probably be accompanied by blowholes, because the "active" slags capable of catalyzing CO formation in solid metal would probably also have released gas bubble formation during the solidification period. However, as cracking is often observed in welds entirely free from porosity, carbon must participate in some other gas-producing reaction occurring at appreciably lower temperature—possibly reaction with atomic hydrogen. According to Zapffe and Sims[15] methane formation from dissolved carbon and hydrogen is possible at temperatures from 600° C and downward. Compared with a cracking temperature of 500° C given by Buchholz and Bettzieche,[24] the combined action of carbon and hydrogen seems to be a fair probable explanation of at least some cases of autocracking. The better crack resistivity of oxidizing electrodes observed by Helin may be accounted for, partly by their spherical slag inclusions which will cause only a slight stress line deformation, partly by the high ratio of nondiffusable to atomic hydrogen found in these welds by Reeve.[14] Regarding the lime-coated electrodes, their low hydrogen and oxygen content together with their convex weld contour would explain their high crack resistivity from either of the hypotheses mentioned above.

Although most of the commonly used steel qualities may be welded with success by use of a proper electrode, it would be desirable to combine the very high quality of lime-coated electrodes with the better welding characteristics of the popular standard electrodes. Among their favorable features may be mentioned their wide current range, deep penetration, high welding speed, correct weld contour and not least their good operating characteristics on low-voltage alternating current. The metallurgical principles which have been discussed above, permit some general conclusions as to the possibility of combining the lime coated and standard types in one electrode.

Like the E6020 and E6030 types, the European stand-

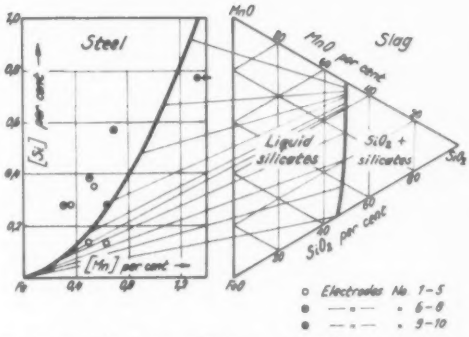


Fig. 8 Deoxidation equilibrium at 1600° C. according to Korber and Oelsen[16]

ard electrodes are characterized by an iron-manganese silicate slag containing various amounts of TiO_2, CaO, MgO and alkalies. According to Barnett,[1] it would be impossible to depart much from the commonly used percentages of MnO, FeO and SiO_2 as this would not give a correct slag fluidity. This question will not be discussed here. However, regarding the metallurgical data of the two types it may be safely assumed that the oxygen content of a lime electrode deposit will be lower than in one made with standard electrodes. It has been shown that the oxygen content of the weld metal is governed by the iron oxide content of the corresponding slag. However, an acid slag containing but a few per cent of iron oxide would cause silicon transfer to the molten metal, giving rise to blowholes and autocracks. From the deoxidation diagram (Fig. 8) may be deduced that at a manganese content of, say 0.6% Mn, the silicon content should preferably not exceed 0.2%. A steel bath of this composition in chemical equilibrium with a slag containing about 4% FeO would correspond to 8–19% SiO_2, the exact value depending on the activity coefficient of SiO_2 in that particular slag. In other words, it would be necessary to dilute the iron manganese silicate slag with metallurgical inactive components. But even at 20% SiO_2 the electrode would have lost its character of "standard electrode." Dilution of the slag with titanic acid would lead to an E6013 slag type, and dilution with lime, magnesia, fluorspar or cryolite would give an E6015 slag. The only possible solutions of this problem would be either a completely new metallurgical "slag design" or a solution through compromise, with a silicon content above the desired value.

Regarding the hydrogen content of the deposit, it should be possible to obtain even better results with "standard electrodes" than with lime coated, as the latter produce low-hydrogen welds in spite of their reducing slags.

If the problem of regulating the weld metal's hydrogen content could be solved, the risk of cracks and blowholes should be greatly diminished. However, a practical solution of these problems will probably require years of research work.

Regarding the hydrogen content of the deposit, it should be possible to obtain even better results with "standard electrodes" than with lime coated as the latter produce low-hydrogen welds in spite of their reducing slags.

If the problem of regulating the weld metal's hydrogen content could be solved, the risk of cracks and blowholes should be greatly diminished. However, a practical solution of these problems will probably require years of research work.

Literature

1. Barnett, O. T., *Steel*, 73 (1946).
2. Sjöman, P., *Svetsaren*, **9**, 56 (1944).
3. Apold, A., *Sveiseteknikk*, **1**, 2 (1946).
4. Gustavson, E., *Svetsaren*, **11**, 125 (1946).
5. Magnusson, E., *Dansk Tekniek Tidsskrift*, **72**, 37 (1948).
6. Hafting, F., *Sveiseteknikk*, **3**, 3 (1948).
7. Babcock, D., THE WELDING JOURNAL, **20**, Research Suppl., 189-s to 197-s (1941).
8. Christensen, N., *Tids. Kjemi, Bergvesen Met.*, **7**, 102 (1947).
9. Körber, F., and Oelsen, W., *Stahl u. Eisen*, **52**, 133 (1932).
10. Körber, F., and Oelsen, W., *Mitt. K. W. Inst. f. Eisenforsch.*, **15**, 281 (1933).
11. Chipman, J., *Trans. Am. Soc. Metals*, **30**, 817 (1942).
12. Schnadt, H., "Nouvelles Methodes d'Essai des Aciers et leurs Application aux Constructions Soudées." From *Dansk Teknisk Tidsskrift*, ref. No. 5.
13. Helin, E., *Elektroschw.*, **11**, 162 (1940).
14. Reeve, L., THE WELDING JOURNAL, **24**, Research Suppl., 618-s to 622-s (1945).
15. Zapffe, C. A., and Sims, C. E., *Ibid.*, **19**, Research Suppl., 377-s to 395-s (1940).
16. Flanigan, A. E., *Ibid.*, **26**, Research Suppl., 193-s to 214-s (1947).
17. Mallett, M. W., and Rieppel, P. J., *Ibid.*, **23**, Research Suppl., 748-s to 759-s (1946).
18. Schenk, H., *Physikalische Chemie der Eisenhuttenprozesse*, Bd. I, Berlin (1932).
19. Helin, E., *Svetsaren*, **8**, 1014 (1943).
20. Sloman, H. A., Rooney, T. E., and Schofield, T. H., THE WELDING JOURNAL, **25**, Research Suppl., 39-s to 52-s (1946).
21. van den Blink, *Ibid.*, **26**, Research Suppl., 369-s to 370-s (1947).
22. Zeyen, K. L., and Lohman, W., *Schweissen der Eisenwerkstoffe*, Düsseldorf (1943).
23. Rollason, E. C., and Bishop, E., *J. Iron Steel Inst.*, **158**, 161 (1948).
24. Buchholz, H., and Bettzieche, P., *Stahl u. Eisen*, **60**, 1145 (1940).

The Pressure Vessel Research Committee 1946-49

THE Pressure Vessel Research Committee has created within its working groups the questioning atmosphere in which research thrives, involving the steel maker, the pure scientists, the designer, the fabricator, the inspector and the final user. An evaluation of the work done by this Committee to date requires a clear and realistic perspective, and must of necessity include both practically useful and intangible benefits.

MATERIALS DIVISION CONTRIBUTION

The Materials Division Program at The Pennsylvania State College is a Survey of the published knowledge of the flow and fracture of metals, ferrous and nonferrous.* It was expected to avoid unnecessary duplication on any new research projects which the Division might review. The main product of the program will be:

1. A Bibliography or catalog to the periodical literature on the subjects selected for the period 1937 through 1947. The most pertinent references will be accompanied by abstracts. The data have been carefully indexed and cross-referenced by subject and author in the form of card files.

(EDITOR'S NOTE: The Materials Division has started a movement in A.S.T.M. for finding unpublished data of this kind.)

2. A compilation in a series of tables of such mechanical property data on pressure vessel materials as could be found in the literature of the period covered by the Survey. This section of the Survey has not so far found the periodical literature to be a fruitful area for particular data on the materials specified for use in pressure vessel construction, other than for atmospheric temperature in practically noncorrosive service.
3. A written Report which will be in effect a digest of this Survey which was specifically directed toward the discovery of possible relationships between the ductility measures of metals within usable temperature ranges, and their resistance under impact and fatigue loadings. The Report was planned to be not so much a recitation of known facts or beliefs about flow and fracture as an attempt to draw up a logical pattern into which these facts would fit, and thus more clearly indicate what is lacking to make this knowledge applicable to practical engineering problems.

DESIGN DIVISION CONTRIBUTION

The work initiated at Purdue University, under the Design Division, while of necessity of a selected application, should have a broad general interest. Results now available show that theoretical stress analyses by the most accurate mathematical methods developed will check closely the measured stresses near commonly used details having similar points of discontinuity.

This report has been prepared by **Walter Samans** and **B. E. Rossi**, Chairman and Executive Secretary, respectively, of the Pressure Vessel Research Committee. It embodies the many ideas and thoughts on the subject submitted by several members of the Committee.

* Although the projects authorized under the Design and Fabrication Divisions are 100% on carbon steels, alloy steels and nonferrous material tests will follow in due course.

Therefore, this technique can be likewise applied to more specific design problems with less difficulty than before.

The Design Division has made satisfactory progress on the main question of head juncture to shells. This was thought to be predominantly needed to determine the detailed procedure by which further tests should be projected.

The Division is following a policy of limiting first expenditures to completing a few problems rather than doing a small amount of work on each of a large number of problems. While this policy may cause some to feel that some problem of particular interest to them is being neglected, it is felt by P.V.R.C. that a few really concrete results will be of more use in the future, and require less back-tracking on retests.

On the theory of formed heads and their junctures to a cylindrical shell and to which other transitions in cylinders and shapes in composite heads are kin, the Design Division has planned and guided the following activities:

1. Listed and studied the more noteworthy previous investigations. The literature survey revealed that several approximate theories, each of which had a considerable credence of its own, were essentially one and the same analysis, involving different nomenclatures. As a part of the literature review, these were all brought together and found to be consistent with the Love-Meissner approximation.

   The comparison of mathematical treatment was first developed and contributed by W. R. Burrows of the Standard Oil Company of Indiana, who also:

   (*a*) Established matrix methods for the determination of boundary (juncture) conditions.

   (*b*) Established approximate and accurate formulas for the most commonly used heads with the exception of the ellipsoidal head where there has now been developed an approximate formula requiring an experimental confirmation.
2. Obtained experimental confirmation of the theory of the conical head.
3. Made good progress toward the solution of the pattern for maximum unit stress of the conical head juncture as a typical detail of form in pressure vessel shape.
4. In particular, for the research project at Purdue University, Appendix A shows information which has been developed as a result of this work, and References 3, 4, 5 and 6, Appendix "B".

In summary, the Design Division believes that the projects further planned will lead to a much improved picture of safe stresses in all kinds of pressure vessel heads, transitions in cylindrical shells, opening reinforcements and externally imposed loadings. The over-all results now being obtained are thought to be sufficient to justify present efforts and expenditures.

FABRICATION DIVISION CONTRIBUTION

The work of the Fabrication Division should be of special interest to industry. The effect of cold deformation and aging on pressure vessel carbon steel is very important in claims for failure of steel in fabrication, as well as in subsequent service.

The most significant contributions of the Fabrication Division project at Lehigh University, regarding pressure vessel materials as affected by fabrication processes, are given below.

Fabrication operations have been simulated by applying uniaxial prestrains of varying degree and direction, by applying various degrees of heat treatment after the prestrains, and by butt welding both strained and unstrained material, following welding by different postheats. From such prepared materials various types of specimens were cut. (For details on this project, see references 7–9 in Appendix B.)

1. A determination was made of the variation of strength, ductility and notch-sensitivity within heats of rimmed and killed steels commonly used in pressure vessels.
2. The effect of these simulated fabrication operations on strength and ductility properties was studied. Strength is raised and ductility lowered to varying degrees by all plastic prestraining. Postheating at 500 and 800° F. produces even lower ductility. An 1150° F. postheat usually results in a slight increase in ductility, while normalizing at 1600° F. restores the ductility to its as-rolled level. Stress-strain characteristics were found to vary with direction of stress and degree of overstrain. The degree of variations in stress-strain characteristics found here should be an important factor in helping to determine stresses to be used in design.
3. A study was made of the effect of fabrication operations on notch sensitivity. Notch sensitivity is noticeably affected by deformations as low as 1%, and increases with deformations up to 10%. Heating to 500 or 800° F. offers no opportunity of improvement in welded or unwelded material, and may be highly detrimental because of a strain-aging effect. Postheating of a welded deformed material to 1150° F. provides only slight improvement, while normalizing restores or improves on as-rolled notch-toughness. Treatment at 1150° F. is definitely beneficial to deformed and welded material, particularly after a low-heat input weld. Normalizing at 1600° F. wipes out prior heat and strain effect.

A steel's response to welding cannot be determined by a study of the prime plate. Welding can cause the transition temperature to rise as much as 150° F. Higher heat inputs usually result in a smaller rise. Material which has been prestrained is just as weldable as prime plate. The notch-toughness of thick plate is reduced more by welding than is that of thin plate.

This was determined by machining all notched bend specimens to identical dimensions after welding. (NOTE: These results will be covered in a Report now being prepared by the Lehigh University Project Staff.)

The continuation of the work of the Fabrication Division with the use of higher strength steels, including alloys, is contemplated and should be an important contribution.

With regard to the Subcommittee on Tests on Cold Formed Heads, all of its research work was conducted by the cooperating companies at their own expense. It is believed that the data collected to date have value and that when the currently planned tests are completed, it may be possible to make a recommendation which will have even greater value to industry.

INSPECTION AND TESTING DIVISION CONTRIBUTION

The activities of the Inspection & Testing Division have been rather limited previous to 1949. However, questions relating to inspection and testing were not entirely neglected, because these are closely related to the work of other Divisions, and naturally were reviewed at the meetings of the other three Divisions.

A research project to determine whether both Hydrostatic and Hammer Testing are beneficial, or whether either is harmful to any degree is now under active consideration. Fatigue Testing, as far as it may apply to some services for pressure vessels, has been discussed but not to any definite conclusion.

CONTRIBUTION OF THE SPECIAL COMMITTEE ON INCREASED DESIGN STRESSES

Some representatives of the steel industry and other interests have shown an alert interest in the project of the Special Committee on Increased Design Stresses. Particularly on the increased and more effective use of alloy steel, the keynote of the last Metal Congress in Philadelphia may be behind this interest in the Special Committee's work.

The Special Committee meeting on November 17, 1948 included some 50 representatives of steel companies, pressure vessel fabricators and users, research organizations and other interested groups. It is expected that these companies will continue to support this activity in the future. In this connection, any contributions made by the individual companies are expected to be direct and in kind, and the P.V.R.C. is ready to continue to furnish the help of its administrative staff organization.

The groundwork for possible research programs under the advisory guidance of this group is now being planned.

OTHER CONTRIBUTIONS

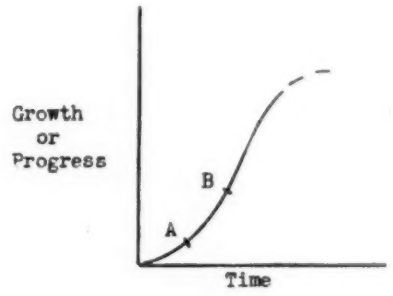
There is one other fair basis for the evaluation of the contribution made by the P.V.R.C.—namely, the educational value. In the P.V.R.C. project groups, there are several combinations of selected industrial engineers actively concerned with one or more of the practical applications of the many problems involved. There are a few of the best scientifically trained engineers with basic knowledge of the fundamental theories in the field, which happens to be a very broad one as it involves several related branches of science. With the interchange of ideas from both of these groups, their close cooperation cannot but help to raise the general level of quantitative thinking.

The indirect return from this procedure by these engineers to the contributing companies will in some cases be greater than the direct value of the research results. It will alternate between these objectives, and in total will enhance the ability of the engineers taking an active part in the work.

CONCLUSION

Some, no doubt, may insist that efficient research shall quickly find directly usable results. They may point out that practically all that is reported for the projects at Lehigh and Purdue Universities has been previously known to some degree, they simply having again verified by these tests the classic knowledge on elastic strain analyses, without touching the core of the problem of plastic yielding. Considering, however, that the groundwork done on selected pedigreed steels on a long-range view is much more appropriate, final judgment might well be withheld until further stages of the projects are reached.

The growth of any new organization follows a life or progress curve similar to a normal biological evolution, as shown in a transformation "time-rate" curve, thus:



At present, P.V.R.C. is at some point such as *A*. In another two or three years it should reach point *B* with adequate nourishment and care that promising growing youth requires. The Committee has now assembled an excellent machine which provides a mechanism for accomplishing useful results. Given two or three more years of support, the results should satisfy all concerned.

It is believed that the P.V.R.C. can take credit for an

honest desire and a concerted effort to learn how to make better pressure vessels. Its investigations have stirred up much new thought and have made clearer a number of problems to pressure vessel manufacturers and users. The results obtained to date and those which will be obtained when the first investigations are carried further along, will more than justify the cost and the continued support of industry.

Appendix A

DESIGN DIVISION CONTRIBUTION—DETAILS OF RESEARCH PROJECT AT PURDUE UNIVERSITY

(*a*) The preparation of the 8-in. diameter test models revealed that they could be machined to a very close tolerance in the knuckle region either with or without a definite knuckle radius. The results of tests on these vessels indicated that, when the radius was very small, the measured elastic stresses were in very close agreement with those computed by the Love-Meissner approximation. The peak stresses measured in the knuckle region, when a knuckle radius was present, were somewhat smaller than those predicted by the approximate theory for no knuckle.

(*b*) Using the more complete theory developed by Burrows which accounts for variation of stress at the head-cylinder juncture region, the test results indicate a closer agreement with this theory than with the approximate theory for no knuckle.

(*c*) The test results indicate that plastic flow in the knuckle region starts at pressures somewhat below the allowable working pressure for the vessel determined by the rules in Section VIII of the A.S.M.E. Code.

(*d*) Re-tests of an 8-in. diameter model (No. 2) after considerable plastic deformation had occurred, indicated that the stress changes in the vicinity of the intersection without a knuckle, after the vessel has been subjected to test pressure of at least one and a half times the working pressure, are of the same general character and distribution as found for the original annealed and unstressed vessel. The magnitude of the maximum stress due to load in the knuckle was only slightly greater than the corresponding stress due to load in the annealed vessel.

(*e*) The tests on the 48-in. diameter vessel revealed that the general trend of stresses in these vessels was in close agreement with that in the 8-in. diameter models and with the approximate theory.

(*f*) Fabricating irregularities after surface grinding to the extent encountered in these vessels cause only slightly greater apparent stresses than occur in comparable places where no irregularities exist.

In addition to head theory, the theory of openings and the theory of external loads are now under study.

(For details of the above, please see references 3–6, Appendix B.)

Appendix B

BIBLIOGRAPHY OF REPORTS RESULTING FROM PVRC WORK 1946–49

The Pressure Vessel Research Committee, being a relatively young committee, does not have many reports to show. However, the following reports have resulted from its work:

General

Reference No.

1 Three Annual Reports to W.R.C. presented on Oct. 1, 1946, 1947, 1948.

2 Twelve Quarterly Reports—Progress Reports by P.V.R.C. to W.R.C., presented from Sept. 30, 1946 to June 30, 1949, inclusive.

Design Division

3 "Method and Techniques for Calibrating the SR-4 Strain Gage Under Hydrostatic Pressure," by H. L. O'Brien, June 1947.

4 "Discontinuity Stresses in Pressure Vessels," by E. Wetterstrom, June 1947.

5 "A Survey of Pressure Vessel Design Literature" (Final Report), Purdue University September 1947.

6 "Pressure Vessel Design Theory on Measured vs. Computed Stresses in 'Head to Shell' Juncture," by R. G. Sturm, H. L. O'Brien, E. Wetterstrom and J. Evans, Purdue University Quarterly Progress Report, Oct. 1, 1948 to Dec. 31, 1948. (Publication under consideration by the W.R.C.)

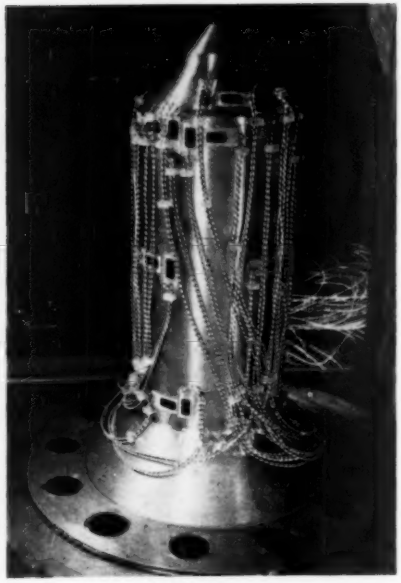
Fabrication Division

7 "A Comparison of Notch Tests and Notch-Brittleness Criteria," by C. J. Osborn, A. F. Scotchbrook, R. D., Stout and B. G. Johnston, Aug. 16, 1948. (Published in the January, 1949 issue of THE WELDING RESEARCH SUPPLEMENT.)

8 "Within Heat Variation of Composition and Properties in a Rimming and an Aluminum-Killed Steel," by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston, Oct. 22, 1948. (Published in the May 1949 issue of THE WELDING RESEARCH SUPPLEMENT.)

9 "Effect of Plastic Strain and Heat Treatment on the Tensile and Notch Properties of a Rimming and a Killed Steel," by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston, Nov. 20, 1948. (Published in this issue of THE WELDING RESEARCH SUPPLEMENT.)

Several other valuable reports are now in preparation and will be released in the near future.



PRESSURE VESSEL RESEARCH COMMITTEE

Conducts Tests at Purdue University

Above: External gauges on model tank before testing.

Right: Model tank after bursting. Opening shown at center.

The accompanying views show one of the model tanks which was tested at Purdue University for the Pressure Vessel Research Committee. The object of these tests was to determine a method of designing cone-cylinder junction of pressure vessels both with and without a transition knuckle or torus.

The investigation is both analytical and experimental and includes strains which are plastic as well as those which are elastic.

For the strain gauge test of this model, Seventy-Two SR4 gauges were located as shown above. The vessel was filled with water and pressure was applied to the inside in 100-lb. increments. The model burst suddenly at 2,750 lbs.

The Pressure Vessel Research Committee develops information and data which will lead to better, safer and more economically constructed pressure vessels. Materials-suppliers, manufacturers, and users of pressure vessels, insurance companies, and several branches of the government, are cooperating in the research.

For further information apply to Welding Research Council, 29 West 39th Street, New York 18, N. Y.

150 FEET
of Everdur Welded Seams
IN 4,000-GALLON LIQUID OXYGEN TANK

L'Air Liquide Society Montreal, Canada, fabricates large Everdur storage tank for U.S. coal mine by inert-gas-shielded arc welding

FOR FASTER WELDING, at lower amperages, and without jigs, L'Air Liquide Society decided on Argowelding for this Everdur* tank. Water-cooled, manually-operated torches were employed with standard D.C. welders on straight polarity for a total of more than 150 feet of seams.

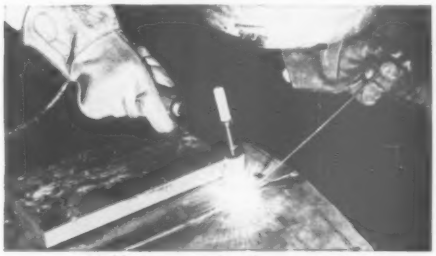
To secure the six-foot discs required for the heads**, Everdur semi-circles were welded with strips of parent metal and the resulting circles dished to a 13" radius and lipped. Girth seams, longitudinal seams and welding of the heads to the shell were completed with Everdur 1010 welding rod.

For detailed information on high-strength, corrosion-resistant Everdur Alloys, write for Publication E-5. Anaconda Publication B-13 discusses Anaconda Welding Rods and their applications.

**Circles up to 156" dia. available from The American Brass Company's U.S. mills.

*Reg. U.S. Pat. Off.

Semi-circles are welded together to form tank head blanks



Welding seams on liquid oxygen tank

Photos, Courtesy Canadian Liquid Air Co., Ltd., Montreal, Canada

ANACONDA
from mine to consumer

Anaconda
WELDING RODS

THE AMERICAN BRASS COMPANY
General Offices: Waterbury 88, Connecticut
Subsidiary of Anaconda Copper Mining Company
In Canada: ANACONDA AMERICAN BRASS LTD.
New Toronto, Ont.

Product "customer-value" built up with flame hardening

THE THEW SHOVEL COMPANY, Lorain, Ohio, wanted to improve the wearability of the sheave throats on Lorain power shovels and cranes, which are located at the upper end of the boom. By so doing, the company felt it would reach the acme of "owner-benefit" in its finished product — the value of a longer lasting part subjected to severe wear.

A. B. Neiman, Airco Technical Sales Representative, recommended oxyacetylene flame hardening. With this modern process, hardening could be localized to the sheave throat, *without* affecting the balance of the sheave's ductility. This was highly important for finished machining. Using a set-up of three Airco No. 4383 torches, with hardening tips especially designed for this job, three sheaves are simultaneously hardened to a predetermined degree that insures maximum wear-resistant qualities.

Since flame hardening was introduced, the company still has gone further in its efforts to increase the customer-value of its products by expanding this modern, localized hardening process to include: gears, jaw clutches, and other parts requiring longer "in-service" life.

• • •

TECHNICAL SALES SERVICE — ANOTHER AIRCO PLUS-VALUE FOR CUSTOMERS

To assure its customers of high efficiency in all applications of the oxyacetylene flame or electric arc, Air Reduction makes available the broad, practical experience of its nationwide Technical Sales Division personnel. The collective experience and knowledge of these specialists has helped thousands to a more effective use of Airco processes and products. Ask about this Airco "Plus-Value" service today. Write your nearest Airco office. (In Texas: Magnolia Airco Gas Products Company . . . On West Coast: Air Reduction Pacific Company)

AIRCO AIR REDUCTION

Offices in All Principal Cities

Headquarters for Oxygen, Acetylene and other Gases... Carbide... Gas Welding and Cutting Machines, Apparatus and Supplies... Arc Welders, Electrodes and Accessories